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Insights Into Transportation Inefficiencies In Global Automotive Supply Chains: The Role Of Technology, Environment, And Regulation

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Abstract
Transportation operations form a vital component of cost efficiency, operational stability, and environmental responsibility within the global automotive industry. This paper critically examines the current transportation practices shaping the sector, moving beyond incremental improvements to address deeper structural inefficiencies and strategic gaps. It highlights the limited integration of telematics, ERP, and TMS systems especially in developing economies as a key barrier to modernization. Environmental challenges arising from conventional transport modes, the limited impact of certain sustainability initiatives, and the underutilization of reverse logistics are also analyzed. Drawing insights from recent supply chain disruptions, the study identifies core weaknesses such as rigid contracts and excessive centralization. Furthermore, it evaluates the effects of regulatory inconsistencies, rising compliance costs, and workforce shortages alongside the growing role of gig-based logistics models. The paper concludes that the future of automotive transportation depends on a comprehensive restructuring of logistics networks centered on efficiency, resilience, sustainability, and international coordination.

Keywords: *Automotive industry; transportation efficiency; supply chain resilience; sustainability; reverse logistics; logistics optimization*

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I. Introduction

Transport is an essential enabler for the automotive industry, enabling every part of the manufacturing and distribution of motor cars. In effect, transport enables raw material producers such as steel, plastic, and electronics companies to tiered component makers, assembly plants, and ultimately dealerships and final customers. It is therefore as much a support activity as part of value creation, stockholding stewardship, and customer service [1, 2]. Modern car manufacturers adopt lean production philosophies, such as Just-in-Time (JIT) and Just-in-Sequence (JIS), to maximize efficiency, reduce work-in-process inventory levels, and provide rapid responsiveness to market demand [3]. In JIT, components arrive "just in time" to be installed, thereby reducing storage costs and the risk of obsolescence [4]. JIS is one step ahead by not only assuring timely delivery of parts but also in the same order required on the production line, thereby allowing efficient assembly processes and the least internal handling [5]. These requirements put transportation networks under tremendous pressure to perform with perfect precision; any deviation of even a few hours can necessitate costly line shutdowns and backup logistics movements to keep the production process running [6].

The worldwide scope of modern-day automotive supply chains makes these obstacles even greater. Modules can start in East Asia, be partially assembled in Central Europe, and be shipped as complete kits to Indian or North American assembly facilities. This form of fragmentation increases cost competitiveness and specialization but makes the supply chain susceptible to cross-border delay, regulatory pressure, and currency or geopolitical risk [7]. For instance, bottlenecks within one of the most important container facilities will ripple throughout the system, holding up raw materials and triggering costly air-freight "rescue" shipments to maintain production schedules [8]. Indeed, transportation disruption, whether due to severe weather, labor negotiation, or infrastructure failure, immediately impacts automakers' bottom line and their reputation. The Tōhoku earthquake and tsunami in Japan severed access to critical electronic components, and overseas automobile manufacturers closed facilities and estimated total revenues lost of more than US$20 billion [9]. Routine glitches, such as chassis deliveries in customs or railroad freight corridors with bookings too tightly filled, become rushed shipping overcharges, overtime, and rescheduling fees. These indirect costs negate the cost advantages that lean practices were supposed to generate [10]. In addition to cost and continuity, transport also affects the sustainability of the automobile industry. Excessive use of long-distance trucking and air freight generates high levels of greenhouse gas emissions as well as air pollution [11]. As standards become stricter and consumers demand to go green, manufacturers must balance the cost of just-in-time (JIT)/just-in-sequence (JIS) delivery with cleaner logististics alternatives like intermodal rail, load-optimization scheduling, or carbonoffsetting plans. Deployment of information technologies, including Internet of Things (IoT), telematics, and advanced transport-management systems, can enable increased visibility and forecasting control over logistics flows [12]. Real-time monitoring would alert managers to impending delays, enabling dynamic routing or consolidation of shipments [13]. In the sector, technology adoption is, however, uneven. In most plants and 3PL firms, legacy systems are still present in data silos, suppressing end-to-end integration and decision-making. Cybersecurity threats to networked fleets and port terminal systems impose another layer of risk, including risk of crippling ransomware attack or data exposure [14]. Transportation in the automotive industry has generally evolved from a back-office to a competitive strategic driver. Its role is not merely product movement but also cost management, production flexibility, risk mitigation, and sustainability. With lean manufacturing putting ever more exacting demands on logistics precision and ever more intricate worldwide networks, automakers are challenged to design transportation plans that are at once resilient, responsive, and sustainable. Understanding these demands provides the basis for a critical examination of prevailing practice and the exploration of novel, system-based solutions[15].

The complexity of modern car manufacturing has expanded across geographical horizons, reliant on global, scattered supply chains and manufacturing hubs. Thus, the auto industry is more dependent than ever on coordinated, responsive, and reliable transport arrangements [16, 17]. However, despite significant investment in logistics infrastructure and information technologies, many transportation practices remain beset with operational inefficiencies, environmental unsustainability, and systemic vulnerability [18]. With the typical car having thousands of different parts from different regions, even small transportation disruptions cause line stoppages and profitability problems. As the automotive market grows, new markets and more customized production strategies, transport must adapt to preserve this extra complexity [19]. This study will critically review the role of transport within the automobile sector. It will address discovering operation inefficiencies, technological deficits, sustainability issues, and weaknesses of the transport system in the context of global disruptions. Analysis covers inbound logistics (supplier to factory) through internal logistics (within factories) to outbound logistics (factory to market).

Challenges and Strategic Interventions in Automotive Transportation Logistics

Motor vehicle transportation network operating inefficiencies are caused by disintegrated logistics processes, excessive dependence on road freight, ineffective utilization of intermodal transport, and Just-in-Time vulnerabilities. The complexity of multiple-layer supply chains normally leads to delays, sporadic shipment visibility, and extended lead times. Beyond this, ineffective route planning, congestion, and driver shortages also lead to increased costs as well as decreased delivery reliability. Over-reliance on road transport, particularly in nations with underdeveloped sea or rail modes has increased emissions and irregular transit times [20].

Technologies are primarily poor real-time information sharing, bad digital platform interoperability, and slow adoption of Industry 4.0 innovations that radically undermine supply chain responsiveness and agility. Most automotive companies remain based on legacy systems that are still out of synchronization between logistic service providers, OEMs, and suppliers and leading to data islands and out-of-sync activities. For instance, a lack of end-to-end transportation management systems (TMS) results in not being able to capitalize on the chance to maximize routes and consolidate loads together [21]. Further, gaps in IoT deployment postpone predictive maintenance and real-time monitoring, resulting in lost downtime and increased disruption risks.

Worldwide auto supply chains are vulnerable to geographic dispersion of suppliers, geopolitical tensions, reliance on unique regional nodes (i.e., semiconductor production in East Asia), and lean buffer inventories based on production philosophies. The COVID-19 pandemic revealed the vulnerability of globally drawn-out just-in-time chains where collapse at one node can shut down complete assembly lines [22]. Other system risks are container shortages, port congestion, workers' strikes, and inclement weather, all of which can cause part delivery delays and interfere with synchronized manufacturing streams. Furthermore, cyber-physical threats such as computer system ransomware attacks appear as an increasing weakness. Strategic measures involve embracing strong logistics structures, several sources of suppliers, regionalization of manufacturing where possible, and strategic investment in transportation systems. Incorporating AI-powered demand planning, blockchain for transparency, and IoT for real-time tracking can enhance flexibility and transparency.

Environmentally, there would be a change to green logistics, i.e., electric vehicle fleets, shifting modes to water, rail, and carbon-free warehouses, and emissions would decrease. There would need to be collaboration between OEMs, logistics service providers, and governments to enable circular logistics and collaborative transport platforms. Scenario planning, digital twins, and simulation-based stress testing can also enhance supply chain resilience [23]. It should be incorporated not only within the practice of transport but also into product design and life cycle logistics. This review was guided by the following research questions:

RQ1: How are emerging and fragmented regulatory environments and rising compliance costs affecting the efficacy of cross-border transport and strategic pairing in automotive supply chains?
RQ2: What strategic changes and innovations need to be driven to enhance the resilience, sustainability, and forward-readiness of global automotive transport networks in the case of systemic risks and labour militancy?

II. Methodology

Search Strategy and Inclusion Criteria

The systematic review was conducted to critically assess transportation inefficiencies in the world auto supply chain, with a special focus on technological, environmental, and regulatory factors. Key scholarly repositories and databases were searched for literature with only English language sources. An initial pool of 177 records was achieved. After filtering out languages, 172 English-language publications were retained. For context relevance to contemporary global logistics movements and technological developments, only articles from between 2014 and 2024 were considered. This date filter reduced the pool to 89 articles.

Document Type Filtering

To maintain academic credibility and highlight peer-reviewed sources, only sources that were marked as "Articles" (and not books, book chapters, reviews, or conference proceedings) were utilized. This left 46 appropriate journal articles.

Relevance to Subject and Final Selection

Further screening was conducted by subject matter. Only publications in the Business, Management, and Accounting subject category were considered. After this domain filter was applied, 15 articles were chosen for further thematic analysis and review (**Figure 1 & Table 1**).

Review Protocol

The review process adhered to PRISMA. A four-step screening protocol was employed:
1. Identification (database search and duplication),
2. Screening (title and abstract),
3. Eligibility (full-text assessment),
4. Inclusion (relevance of subject and methodological soundness).

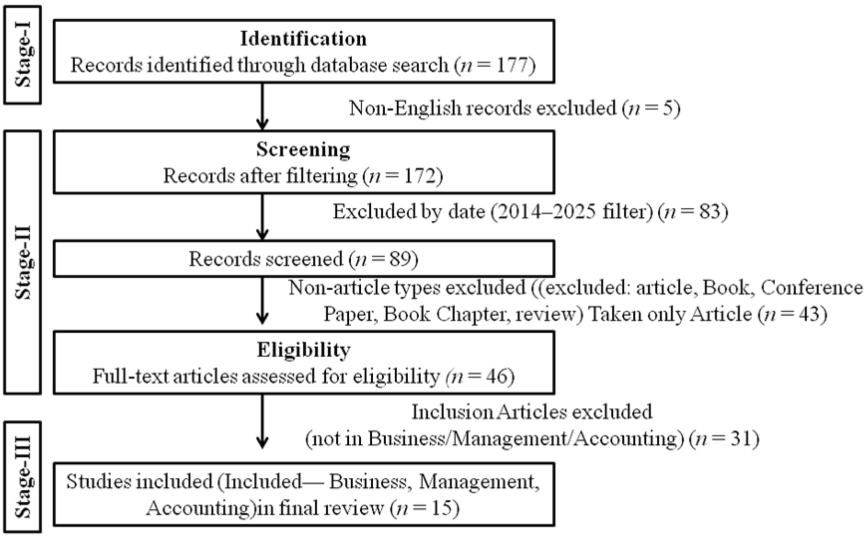

Figure 1. PRISMA flow diagram illustrating the process for selecting studies on transportation in the global automotive supply chain

Table 1 Articles on transportation in the global automotive supply chain

No.	Title	Source Title	Focus Area	Methodology / Approach	Reference
1	An optimal purchase decision of reusable packaging in the automotive industry	*Sustainability (Switzerland)*	Reusable Packaging, Inventory Strategy	Optimization Model	[24]
2	Environmental	*Supply Chain*	Environmental	Empirical Case	[25]

	management: the role of supply chain capabilities in the auto sector	*Management*	Strategy, Capability Building	Analysis	
3	Blockchain technology for enhancing traceability and efficiency in automobile supply chain—a case study	*Sustainability (Switzerland)*	Digital Traceability, Blockchain Integration	Case Study	[26]
4	The Importance of the New Silk Road in the Hungarian Automotive Supply Chain	*Sustainability (Switzerland)*	Geopolitical Supply Chain Shifts	Regional Supply Chain Analysis	[27]
5	Modelling the Returnable Transport Items (RTI) Short-Term Planning Problem	*Sustainability (Switzerland)*	Reverse Logistics, Packaging Logistics	Modeling	[28]
6	Modeling a Reverse Logistics Supply Chain for End-of-Life Vehicle Recycling Risk Management: A Fuzzy Risk Analysis Approach	*Sustainability (Switzerland)*	ELV Recycling, Risk Management	Modeling	[29]
7	MCDM Approaches for Supplier Selection in Sustainable Supply Chain Management	*Sustainability (Switzerland)*	Sustainable Sourcing	Multi-Criteria Decision Making (MCDM)	[30]
8	Financial performance measurement framework of automotive supply chains	*International Journal of Procurement Management*	Financial Performance, KPIs	Framework Development	[31]
9	Logistics implications of electric car manufacturing	*International Journal of Services and Operations Management*	Electric Vehicle Logistics	Conceptual Analysis	[32]
10	Overcoming Barriers to Digital Transformation towards Greener Supply Chains in Automotive Paint Shop Operations	*Sustainability (Switzerland)*	Green Digital Logistics	Case-Based Study	[33]
11	On the importance of service performance and customer satisfaction in third-party logistics selection: An application of Kano model	*Benchmarking*	3PL Selection, Customer Satisfaction	Kano Model	[34]
12	Performance-based contracting in service supply chains: A service provider risk perspective	*Supply Chain Management*	Risk-Based Contracting	Analytical Framework	[35]
13	Grocery retail operations and automotive logistics: A functional cross-industry comparison	*Benchmarking*	Cross-Sectoral Logistics Insights	Comparative Study	[36]
14	Developing resilience strategies amid supply chain risks in the automotive industry: A stakeholder theory perspective	*Business Strategy and the Environment*	Supply Chain Resilience	Stakeholder-Based Analysis	[37]
15	Enhancing supply chains agility–The development of logistics capabilities by automotive producers in Central and Eastern Europe following Russia's invasion of Ukraine	*Society and Economy*	Agility, Geopolitical Impact	Regional Case Study	[38]

III. Result & Discussion

Mapping the Automotive Transport Ecosystem

The automotive transport ecosystem consists of a tightly choreographed, multi-stage transportation network that crosses continents and incorporates thousands of distribution hubs, manufacturing plants, and suppliers [36]. From raw material procurement to end delivery of the vehicle, every step of logistics adds value and is synchronized through tightly coordinated transportation [24, 31, 39]. With the globalisation of the automobile industry and changing consumer needs, the transportation system must respond to handle more complexity, variability, and velocity.

Inbound, In-Plant, and Outbound: Key Logistics Components

The automotive logistics system is generally segmented into three main elements: Inbound logistics is the process of moving raw materials and parts from the suppliers to the factory. Metals, plastics, electronics, and pre-fabricated units such as engines and seats are some examples. Inbound logistics is normally regulated through JIT systems and coordinated delivery schedules to reduce storage needs and simplify production [40]. In-plant logistics is the movement of goods within the plant. It involves in-plant distribution of parts to assembly lines, sub-assembly handling, and work-in-progress transportation from one workstation to another. More and more, Automated Guided Vehicles (AGVs), conveyor systems, and warehouse robots are being utilized to streamline in-plant transportation operations[32, 41, 42]. Outbound logistics is the movement of completed cars from assembly to distribution centres, dealerships, or end users. It is based on various transport modes such as road, rail, and ocean. Outbound logistics has to make trade-offs between cost minimization and minimizing delivery lead times to satisfy customers [35, 43]. Each of these logistics stages constitutes a continuous stream that requires proper coordination in order to prevent delay and cost accumulation.

Multi-tiered Supplier Integration and Transport Implications

The supply chain of the automotive industry is usually composed of more than one tier of suppliers. Tier 1 supply OEMs directly, while Tier 2 and Tier 3 suppliers supply components to upper tiers. The multi-tiered structure is more complex to plan for transportation because transportation of components from one tier to another needs to be coordinated in order to facilitate final assemblies without dissonance. For instance, a delayed shipment of a small electronic component may propagate cascading bottlenecks upstream in the supply chain, slowing Tier 1 module assembly and thus OEM production lines. Integration of logistics information across tiers is limited, and much remains undertaken through disconnected systems or hand scheduling, risking misalignment [44, 45]. This study emphasized that environmental management in the automotive sector depends heavily on the strength of supply chain capabilities. Their findings support the present research observation that operational inefficiencies can undermine sustainability goals despite technological advancements [25]. Transportation implications also include reverse logistics, packaging, and handling. The OEM packaging procedures must be followed by the suppliers, and they must potentially return reusable containers, which becomes another aspect of logistics coordination. Effective transportation within levels is very important to protect the integrity of JIT and JIS systems [46]. Štreimikienė et al. (2024) described about the applied multi-criteria decision-making (MCDM) methods to supplier selection for sustainable supply chains. Incorporating similar evaluation models could improve decision quality and environmental accountability in transport planning [30].

Globalization and Its Effect on Transport Network Complexity

Globalization of car manufacturing has scattered supply networks and demand chains across spaces. Klug's work on electric car manufacturing revealed how production shifts affect logistics structure and energy use. These insights underscore the need to adapt transportation systems to emerging vehicle technologies [32]. The producers now procure parts from different continents and set up factories in places to lower the cost of labor, gain access to new markets, and mitigate trade risks. Selviaridis & Norrman (2014) examined performance-based contracting and associated risks for service providers. Adopting such contracting models could encourage accountability and mitigate performance gaps observed in automotive logistics [35]. Using stakeholder theory, previous study explored resilience strategies against supply chain risks in the automotive industry. The findings align with this study's emphasis on resilience modelling as a foundation for sustainable transport design [37]. This worldwide reach has heightened the dependency on multi-modal transport systems using road, sea, rail, and air. In addition, trade tensions, varying tariffs, and geopolitical uncertainty have caused international transportation planning to become riskier. Businesses now need to keep backup routes, dual sourcing strategies, and even near-shoring solutions as hedging tools against cross-border disruptions. Globalization, as it created cost benefits, has consequently added considerable volatility and risk to the system of automobile transportation [30, 47]. The previous study highlighted the growing strategic role of the New Silk Road in improving supply chain connectivity for Central Europe's automotive sector. Similar cross-border initiatives could help mitigate the route inefficiencies noted in this research [27].

The Role of Distribution Centers and Warehousing Nodes

Distribution centers (DCs) and warehouses are two of the most important hubs in the automotive transport system. Strategically positioned DCs play several roles: they serve as a buffer against supply-demand gaps, consolidate shipments, and facilitate economical last-mile delivery. They also support value-added services like pre-delivery inspection (PDI), accessorization of vehicles, and customization of packaging [48]. The automakers would usually have local DCs near major markets to shorten the delivery lead time and to be more responsive to the customer. The hubs also become more automated and data-based, leveraging warehouse management systems (WMS), real-time inventory, and predictive analysis to maximize stock levels and dispatch planning. But warehousing does have its downsides, such as limited space, a lack of workers, and increasing real estate prices in cities. Warehousing also introduces an extra handling level, which could increase the potential for damage or loss of goods unless handled with extreme care. With e-commerce business models and direct-to-consumer sales on the rise in the automotive arena (particularly for EVs), DC operations are set to change further, by weaving more into IT infrastructure and last-mile carriers [49].

Operational Inefficiencies and Challenges

Transportation is the linchpin of the motor vehicle industry, serving both as a central element in upstream supply chain management and downstream distribution. Despite being so crucial, transportation operations within the industry are consistently beset by systemic inefficiencies and logistics vulnerabilities. These issues take hold in many different forms, anything from modal imbalances and inferior routing to disintegrated tracking systems and disconnected multimodal coordination. All of these problems reduce the cost efficiency and uniformity of vehicle logistics, particularly within a lean production environment characterized by JIT and JIS production. The subsequent four most significant domains of operational problems are discussed critically in the next section: overreliance on road transport, routing and load usage inefficiencies, intermodal coordination breakdowns, and inadequacies in real-time visibility. By comparing grocery retail and automotive logistics, the authors revealed cross-industry operational parallels. Their comparative insights suggest that automotive logistics could benefit from adopting efficiency models used in other sectors [36].

Overdependence on Road Transport

The automobile sector is still highly dependent on highway-mode trucking of goods. Highway mode accounts for between 60% and 80% of the sector's total logistics movements, especially for end-mile motor vehicle distribution and just-in-time part deliveries. Although road transport provides unmatchable point-to-point coverage with high flexibility, it presents a variety of operating risks in terms of reliability, cost, and environmental performance. Křenková et al. (2023) discussed how automotive producers in Central and Eastern Europe enhanced logistics agility after geopolitical disruptions [38]. This reinforces the current paper's conclusion that flexibility and capability-building are essential for post-crisis recovery. Capacity Constraints and Congestion: Road capacity in the majority of developed and emerging countries is always unr pressure from increasing freight demand. Highways and city transit networks are typically congested, resulting in bottlenecks and unpredictability of delivery times. Truck speeds on main European freight routes average below 30 km/h because of traffic congestion and terminal bottlenecks [50]. Pressure is mounting on manufacturers to lower their overall carbon footprint, continuous use of diesel trucking is increasingly incompatible with environmental pledges and sustainability objectives.

Another urgent issue is the cost volatility in road haulage. Volatility in the price of diesel, toll regimes, and driver availability makes it challenging to estimate costs. This volatility undermines margins or is cascaded down the value chain to suppliers and end consumers [51]. The driver shortage is a persistent problem in most logistics markets, also constraining capacity and increasing operating costs. Though cleaner and less expensive alternatives like rail, inland waterway, and short-sea shipping are available, these remain untapped due to infrastructural deficits, policy rigidity, and operational integration failure [52].

Coordination Failures in Intermodal Transportation

Intermodal transport with a combination of road, rail, and sea has theoretical cost, speed, and emissions advantages. In practice, these advantages are offset by failures to coordinate modal interfaces [53]. Various Contracts and Accountability Shortfalls: Transportation contracts by road, rail, or sea are normally segmented across most auto supply chains and are more likely to be managed by separate departments or intermediaries. In this siloed setup, there are conflicting performance KPIs and unclear accountability in the case of supply disruptions [54]. Delayed movement of goods during transit is obstructed when there is no single command centre to facilitate a quick response and raises demurrage costs. Documentation and Compliance Bottlenecks: Documentation processes like paper bills of lading, customs declaration, and inspection reports create unnecessary delay and administrative inefficiencies. Such inefficiencies cut sharply in cross-border automotive supply chains that cross multiple customs jurisdictions [55].The automotive firms need to create interoperable TMS platforms that undertake multimodal bookings, tracking in real time, and measurement of performance along the transport chain.

Lack of Real-Time Visibility and Control

Real-time visibility to the status and movement of goods is crucial to auto manufacturers who are operating on thin windows of time. Yet, numerous supply chain members particularly lower-tier suppliers are not provided with digital capabilities to facilitate real-time visibility [56]. Telematics Data Gaps: Whereas the majority of original equipment manufacturers (OEMs) install GPS and telematics on their own fleets, subcontractors and component producers usually do not have such systems [57]. Delayed exception handling without predictive analytics and real-time notifications, logistics staff are left to find out about issues only after they've risen to the point of being major ones such as vehicle breakdowns, handoff drops, or customs delays. These firefighting tactics are generally high-cost expedites or plant shutdowns. Broken IT Infrastructure: Even if data for tracking is available, it tends to become broken up on proprietary sites or single-touch dashboards instead of being routed into ERP, warehouse management, or production scheduling software. Fragmentation makes the response strategy hard to automate and requires them to be coordinated manually. It involves investing in Internet of Things (IoT) technologies, RFID tagging, and cloud-based analytics to fill the gaps in visibility[30]. Ada and colleagues demonstrated how blockchain can enhance traceability and transparency in automotive logistics. Integrating such decentralized systems could address current data fragmentation issues identified in this study [26]. Carpitella (2024) reported digital transformation barriers in automotive paint shop logistics and proposed pathways toward greener operations [33]. Such findings reinforce the argument that fragmented digital adoption limits sustainability progress in transport networks.With deployment along with predictive algorithms, these technologies can significantly enhance supply chain resilience and responsiveness [37] [58].

Technology Integration: Gaps and Limitations

The integration of digital technologies in the transportation part of the motor sector has also increasingly become vital to the efficiency, resilience, and competitiveness of the industry. Some of these technologies include the Internet of Things (IoT), Global Positioning System (GPS), telematics, Enterprise Resource Planning (ERP) software, and Transport Management Systems (TMS) that give end-to-end real-time visibility, predictive analytics, and automations across the supply chain. However, while these advantages have been largely recognized, their effective implementation across the automobile industry remains patchy, disorganized, and poorly consolidated, creating lingering operational bottlenecks and new security risks [19].

Adoption of IoT, GPS, and Telematics: Current Situation

Sensor-enabled IoT and GPS monitoring technology hold various potentialities to explore for tracking inventories, vehicles, and assets in real-time. In the vehicle industry, telematics fuel consumption, vehicle diagnostics, route tracking, and driving behaviour becomes prevalent for Original Equipment Manufacturers (OEMs) and Tier 1 logistics providers [59, 60]. Even though all this has improved, adoption is mostly among the large players, and small suppliers hardly ever have technical or financial means to install such devices. Galankashi & Rafiei (2022) proposed a financial performance framework to assess automotive supply chains, linking efficiency directly with profitability [31]. This complements the current research perspective that operational inefficiency translates into significant financial losses. Even when data is being recorded, its integration into decision-making support tools remains underdeveloped. Most companies collect information but fail to utilize it effectively in a bid to develop dynamic routing, predictive maintenance, or exception handling, and consequently minimize the contribution of such technologies. Furthermore, interoperability with heterogeneous IoT devices is still an issue as a result of diverse standards and communication protocols.

ERP and Transport Management System (TMS) Integration Disasters

ERP systems are the focal point of business core procedures like procurement, inventory, manufacturing, and order delivery. ERP operates independently of logistics and TMS platforms in most car supply chains, however, leading to silo operations and lack of coordination. Separate operations of TMS and ERP present the difficulty of uninterrupted integration between them, which prevents real-time sharing of vital transportation information, like shipment status, delay, or route change, therefore compromising on responsiveness and agility. For instance, order changes that have been entered in ERP systems are not always reflected in TMS, leading to mismatches in delivery and production delays. The integration gap also hinders effective capacity planning as well as demand forecasting [61]. Their modelling of returnable transport item (RTI) planning shows how optimization techniques can reduce idle capacity and waste in short-term logistics. This aligns with the study’s finding that better planning tools are vital for achieving efficiency in transport cycles [28].

Data Silos and Single Platforms Deficiency

The automotive logistics network consists of several players OEMs, Tier 1–3 suppliers, third-party logistics companies (3PLs), freight carriers, port terminals, and customs houses each having independent digital platforms [62]. Previous literature described the link between service performance and customer satisfaction in third-party logistics selection [34]. This connection supports the view that enhancing logistics service quality is as critical as improving internal efficiency. This leads to too many producing catastrophic data fragmentation. Without a platform that can provide end-to-end visibility, it is challenging to coordinate, and decisions are taken on stale or stale information. Data silos not only impede information flow but also constrain the capabilities of future analytics and artificial intelligence technologies. Furthermore, differences in forms and reporting processes increase the difficulty to integrate. New technologies such as block chain provide transparent and secure data sharing, yet these have been slow to adopt because of complexity, cost, and regulatory ambiguity.

Digital Logistics System Cybersecurity Threats

With greater digitization, with it comes greater vulnerability to cybersecurity threats. Automotive supply chain infrastructure, mostly cloud-based TMS, telematics, and IoT devices are vulnerable to cyber attacks in the form of ransomware and data breach, systems hijacking, and industrial espionage. The damage of an attack like this can be extensive. A corrupted TMS can devastate routing capacity, direct resources to the wrong location, or pass sensitive customer data. In heavy volume JIT manufacturing settings such as the automotive industry, a system failure of only a few minutes can knock lines out of production and cost millions of dollars in lost business. However, most of the logistics companies, especially small and medium sized companies (SMEs), do not have cyber resilience frameworks or incident response plans that are needed to overcome such attacks. Low cyber security investment in training, outdated software platforms, and open endpoints (like outdated GPS devices or warehouse sensors) are the reasons for the risk. With more and more integration with the supply chain, cybersecurity has to be an integral part of logistics digitization plans [63]. As illustrated in **Figure 2**, automotive logistics is still grappling with a range of digital technology challenges. These include inconsistent adoption of IoT and telematics, lack of system interoperability, poor integration between ERP and TMS platforms, fragmented data systems, and rising cybersecurity risks. Together, these issues disrupt end-to-end visibility, slow down responsiveness, and limit the full potential of data-driven decision-making in the supply chain.

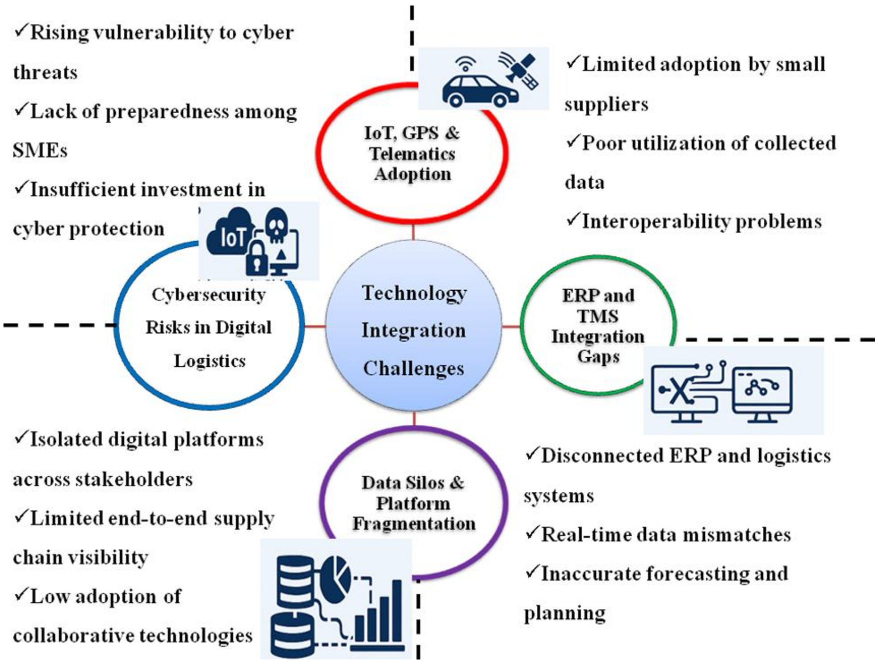

Figure 2. Technology Integration Challenges in Automotive Supply Chains

Environmental and Sustainability Challenges

The transport sector of the vehicle industry is a major source of harm to the environment in the form of greenhouse gas emissions, fleet technology with low efficiency, and a non circular logistics approach [26]. With sustainability as the focal point for operations planning, the industry is increasingly subject to pressure to switch to cleaner, more circular modes of transport. But it advances slowly, constrained by technical, legislative, and organisational momentum [64]. The "Just-in-Time" and "Just-in-Sequence" philosophies, while ensuring inventory efficiency, will typically necessitate deliveries being made more frequently with spare use of vehicles, thereby adding to per-unit emission cost. Further consumer demand for faster delivery in aftermarket services perpetuates this with express shipments, which depend heavily on air freight a transportation mode that contains one of the highest emission rates by unit weight. Even with heightened awareness, most auto manufacturers continue to monitor their transport-related emissions less than they do manufacturing.

Impediments to Transition of Green Fleet (EVs, Hybrid Trucks)

Though electrification offers a workable route to the decarbonisation of transport, adoption in the logistics part of the car value chain is only starting [32]. A shift to electric or hybrid trucks is being held back by a range of practical and structural impediments. Electric trucks are much more expensive than diesel trucks, with payback often taking over five years on a location-dependent and application-specific basis. The majority of logistics companies, particularly small to medium enterprises with narrow profit margins, have little incentive to invest in cleaner technology unless there are tough regulations or financing incentives. The absence of charging points for medium- and heavy duty EVs particularly along intercity freight corridors makes electrification for long-haul operationally unfeasible in most nations. Existing electric truck offerings are accompanied by limited ranges and heavier batteries, diminishing payload capacity a major consideration in automotive parts delivery where tight loads are standard. Even if trucks are biofuel or hybrid powered, their penetration in the market remains too low to change the overall emission trend. Moreover, lifecycle analyses may disregard upstream emissions when producing batteries or generating electricity and therefore compromise sustainability analysis [65, 66]

Reverse Logistics and Circular Supply Chain Deficits

Omosa et al. (2023) reported risk analysis for reverse logistics in vehicle recycling, illustrating how uncertainty management strengthens sustainability. It resonates with this study's call for more robust risk modelling in transport operations [29]. Yet another huge sustainability deficit in car transport is the lack of effective reverse logistics networks. Although there has been better car recycling, the transportation of recoverable parts, packaging materials, and residues back down the supply chain is uncommon and not utilized. Most deliveries return empty in vehicles after delivering finished cars or components, resulting in inefficient capacity and higher net emissions. Packaging Waste: Single-packaging, pallets, and crates are widely used in auto parts logistics despite the existence of reusable substitutes. Planning for transport hardly considers reverse flows for these goods because of scheduling complexity and low visibility [29, 67].

Regulatory, Legal, and Policy Barriers

Transport in the motor industry is not only defined by logistics efficiency and technology, but also by a complex network of regulatory, legal, and policy hurdles. The hurdles usually serve as hidden bottlenecks in cross-border operations, decelerating supply chains, raising operational costs, and lowering responsiveness. Though international trading arrangements and harmonization have sought to simplify automotive logistics, significant regulatory and infrastructural asymmetry still exists. Asymmetry concerns not only transnational auto producers but also tiered producers and third-party logistics firms operating in or between jurisdictions [68].

Cross-Border Inconsistency of Transportation Regulations

Perhaps the most enduring automotive logistics problem is cross-border inconsistency of transport-related regulation and by region. Regulations on axle loads, vehicle dimensions, driver working hours, and road licenses vary widely across countries, complicating international shipments [69]. A truck that meets European Union transport standards, for instance, might not be eligible for road transport in some Asian or African nations based on varying standards on emissions or vehicle specifications. This heterogeneity compels the logistics operators to undertake complicated route planning and fleet administration, usually entailing mode switching, transloading, or other regulatory approvals [70]**.** Furthermore, even within one economic union such as the EU, transport directives implemented on a national level can be unequal, leading to irregular compliance and unpredictability in car shipments. These kinds of regulatory diversities enhance the cost and time factor of cross-border transport, lowering supply chain responsiveness and agility [71].

Environmental Compliance Costs

Due to increasing environmental issues, governments worldwide have set strict policies to eliminate transportation emissions. Although these policies are required for green growth, they impose high compliance costs on the automotive logistics industry. EU's Emissions Trading System (ETS), California's Advanced Clean Fleets rule, and low emission zone requirements in metropolitan cities demand fleet upgrades, alternative fuel usage, and on-stream emission measurement. For instance, conversion of diesel fueled trucks to electric or hydrogen trucks requires a significant amount of initial capital investment, investment in new infrastructure (e.g., charging stations), and potentially operational inefficiency due to the range limitation. Further, meeting standards of emissions quantification and reporting entails digital monitoring equipment and high administrative costs [72]. All these regulations, while good for the environment, have the effect of distorting transportation cost bases and paining small logistics providers disproportionately [73]. **Figure 3** summarizes the most significant environmental and regulatory challenges confronting auto transport today. The industry is under growing pressure to adopt cleaner technologies like electric and hybrid trucks, but massive expense, poor infrastructure.

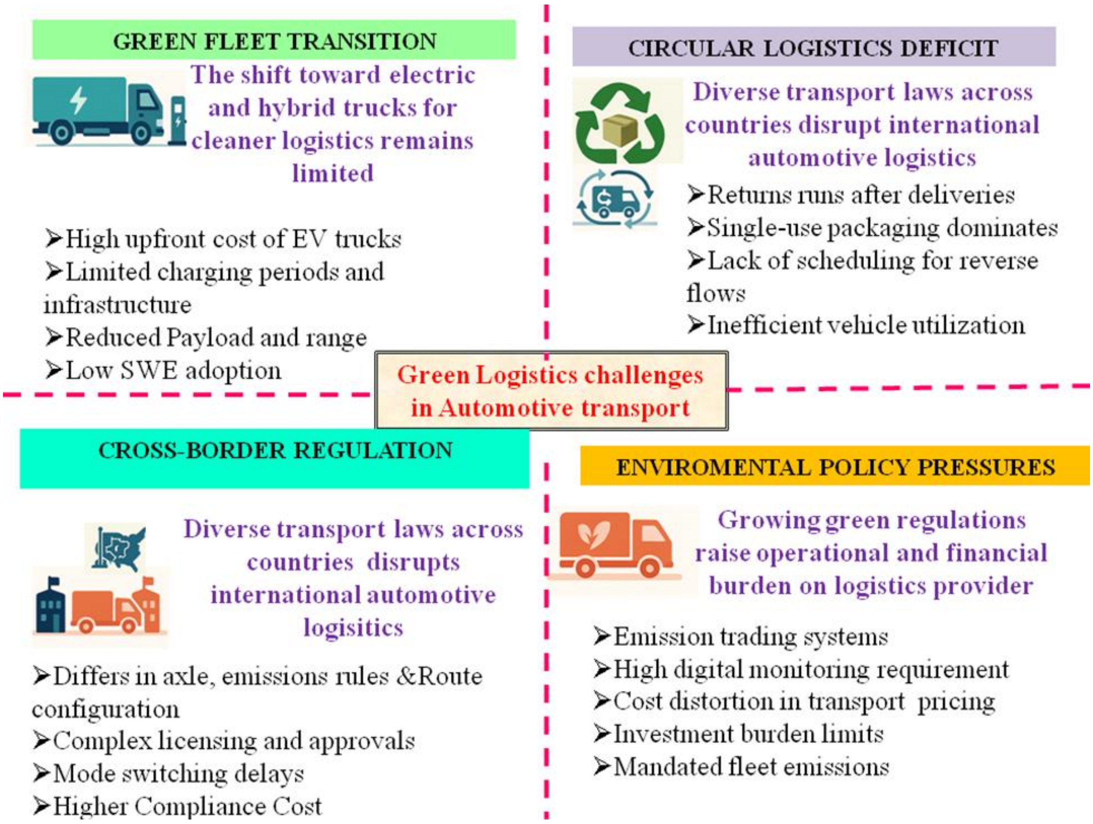

Figure 3. Environmental and Regulatory Challenges in Automotive Supply Chains

Human Resource and Labor Issues

Technology and infrastructure do not just decide the transport efficiency of the automobile sector human resources do as well. Yet the labor base of road freight, and especially logistics, is confronted with extensive and complex issues. These range from shortage of staff to hazardous working patterns, unhealthy working environments, and inadequate implementation of labour rights. As transportation operations are expanding in scale and complexity, these types of human resource issues are the biggest threat to the sustainability and resilience of automotive supply chains [68, 74].

Driver Shortages and Aging Workforce in Logistics

One of the most urgent labour issues in automotive transport is the rising driver shortage of skilled drivers. The logistics sector in the majority of areas is confronting a demographic challenge with an overwhelming majority of commercial vehicle operators reaching the retirement age and scant new entrants replacing them (IRU, 2023). For example, within Europe, nearly 30% of truck drivers are over 55, with the younger generation having diminishing interest in logistics careers due to long working hours, low status, and poor opportunities for career development (PwC, 2022). This shortage is compounded by the stressful work environment, such as non-standard working hours, longer periods of on-road time, and poor social protections. The result is an even more stressed-out workforce that causes slowdowns in delivery and inflation of costs in car transport networks. The problem is particularly severe in just-in-time systems, where minor logistical delays can cause manufacturing schedules to collapse [75–78].

Exploitation and Informalization in Contract-Based Approaches

Among the biggest structural issues in the logistics labour force is increasing informalization of work, especially through subcontracting and gig economy arrangements. Logistics firms, in their desire to reduce costs, subcontract transportation activities to smaller units or independent contractors [79, 80]. Though this creates flexibility for employers, by default, it tends to result in wage restraint, job insecurity, and denial of labour rights to worker [81]. In such systems, transport operators can buy fuel, maintenance, and insurance but be given limited healthcare, retirement, or union representation. Casual contracts also restrict the capacity of workers to bargain collectively or legally complain about discriminatory treatment, providing fertile soils for exploitation (Fair Transport Europe, 2020). The absence of regulation and enforcement in such decentralized systems also further increases the risk of exploitation for drivers in the automotive transport system [82].

Safety, Working Time, and Labour Law Violations

From time to time, workplace health and safety issues are shared among logistics workers. The long working hours, inadequate rest periods, and time-specific injuries generate high rates of accidents that are fatigue-related in the road [83]. Casually enforced labour legislation in these regions provides room for businesses to circumvent provisions addressing driving time, pauses, and occupational health standards. Overscheduled drivers, aside from a greater accident propensity, are also confronted with long-term health problems like cardiovascular illness, musculoskeletal disorders, and psychological tension [84]. Furthermore, enforcement inspections and compliance audits are deficient or easily evaded, especially in cross-border transportation situations where jurisdictional authority is absent. Aside from putting employees in jeopardy, these offenses also degrade the general effectiveness and credibility of the automobile supply chain.

Unionization and Industrial Action Affecting Supply Chains

Although unionization is a possible pathway to the enhancement of working conditions, its functioning in road transport is questionable. Unions in certain nations have been able to secure improved wages, terms of work, and welfare for road drivers. Union density is, however, declining in most parts of the globe, particularly within the informal economy and gig economy [85]. Where union action is still strong, industrial action like strikes or slowdowns have periodically upset car-manufacturing logistics, with massive losses of output. In this instance, seaborne port strikes, lorry stoppages, or warehouse walkouts have all caused supply chain glitches over recent weeks. Although such actions have genuine points, they also illustrate the vulnerability of car manufacturing logistics systems relying on smooth, just-in-time systems. Resolution of this paradox will need not only better labour policy but deeper rethinking about how human work is valued within the logistics economy [86].

Systemic Risks and Vulnerabilities

The motor industry's transport infrastructure, while growing ever more complex, has built into it a variety of systemic vulnerabilities. These are not noticed until highlighted by the mass disruption and the exposure of the fragile and exposed nature of worldwide supply chains. This subsection critically addresses four main areas of vulnerability: global disruptions such as pandemics and raw materials shortage, overcentralization in the warehouses, insufficient fleet and fuel redundancy, and breakdowns in operational transport contingency planning [87].

Global Supply Chain Disruptions

The COVID-19 pandemic provided a harsh reminder of the exposure of the automotive sector to worldwide shocks. Lockdowns, border restrictions, and shortages of labour halted almost all steps of automobile transportation, ranging from raw material sourcing to vehicle delivery. A particularly acute case is that of the semiconductor chip shortage, which brought production lines to a standstill across the world due to the car industry's adoption of just-in-time inventory systems and its relatively low priority ranking among chip producers [87].The pandemic COVID-19 was a global occurrence, inducing simultaneous demand and supply shocks due to conventionally regional supply chain breakdowns. This made the manufacturer close factories, hold up deliveries, and renegotiate with suppliers, all of which translated into billions of revenue forsworn and unmet customer demand [88–90]. The extended microchip shortage, worsened by natural disasters and geopolitical unrest in major production areas, pointed to the shortage of resilience in transportation and source plans throughout the industry.

Absence of Redundancy in Vehicle Fleet Procurement and Fuel Supply

Automotive transport networks also have low redundancies of vehicle fleet suppliers and fuel supply networks. Most logistics providers rely too much on one trucking contractor or a fleet owner, especially in emerging and developing economies. The mono-dependency exposes the system to excess exposures to labour disputes, instability in fuel prices, and equipment shortage (KPMG, 2022). Moreover, the export and long-haul logistics fueling infrastructure is fossil fuel intensive and highly concentrated. Increasing oil market volatility with geopolitically unstable conditions and a lag in electric fleet deployment risks double jeopardy of supply disruption and cost instability. Lack of diversified fueling capacity or strong fleet strategy makes the transportation operation poorly positioned to withstand persistent energy shocks[91] .

Transport Contingency Planning Risk Management Gaps

Despite all these apparent weaknesses, few car makers have formalized and regularly exercised contingency policies for transport failures. Risk management, when it occurs at all, is spread across departments and centered around finance or legal risk, rather than on operational continuity. There is a massive gap in scenario planning, with limited companies running wide-scale disruption tests or having standby logistics partners. Technology like transport management systems (TMS) and predictive analysis is not being appropriately used to stress-test networks for the probability of collapse [92]. Over-reliance in the industry on response measures means that it has no control over when disruptions start. Transition to proactive planning for resilience through multi-sourcing, regional buffer stocks, distributed storage, and transportable contract flexibility is essential in resisting the impending risks. Without this transition, the industry continues to remain vulnerable to cascading collapses due to localized accidents or system shocks.

Strategic and Systemic Recommendations

The recurring inefficiencies and vulnerabilities of automotive transportation systems need more than ad hoc fixing; they need systemic change. These four interrelated strategies, discussed below, collectively set out to make the auto industry's transportation system more robust, more sustainable, and more flexible.

Designing Resilient and Redundant Transport Networks

The COVID-19 pandemic, semiconductor shortages, and international tensions have tested the vulnerability of hyper-optimized supply chains to excessive cost-cutting at the expense of resiliency. Automaker manufacturers and logistics firms need to move towards redundancy based transport network planning where standby suppliers, routes, and modalities are intentionally retained to act as a buffer against interruption [88]. This entails embracing the ethos of "flexible redundancy" investment in diversified supply chains and leverage of real-time transportation knowledge technologies (e.g., IoT based fleet tracking, AI-optimized routing optimization), facilitating rapid reconfiguration of supply chains in disruption [93]. Multiples carrier strategic alliances, rather than single source dependency, can also mitigate carrier type failure.

Transitioning towards Sustainable Multi-modal Logistics

The carbon footprint in transport continues to be an area of concern, and the global logistics sector accounts for around 8–10% of global CO_2 emissions. Manufacturers must drive the transition to clean multi-modal transport through the optimal inter-modal combination of roads, rails, sea, and inland waterways. Rail freight, though slower than road transport, emits much less per ton-kilometer and is best suited to long-distance in-and-out supply chains. Furthermore, electrification of lorries and hydrogen fuel-cell lorries and route concentration plans can reduce carbon emissions without lowering the level of service. Electronic platforms reducing load factors and backhauls with no load the widespread phenomenon in transport of vehicles must be given a priority[94].

Investment in Labour Force, Training, and Technology Evolution

Automation and digitization are transforming logistics but human labour force remains necessary especially for customs brokerage, last-mile delivery, and fleet management. But there is a massive skills gap between what the labour force that is accessible can provide and needs of data-driven logistics systems (World Economic Forum, 2020). To bridge this, the auto logistics sector should invest in upskilling employees, particularly in areas like digital supply chain management, AI-routing, and green logistics operations. Collaborative vocational training between manufacturers, logistics companies, and educational institutions can provide employees with flexible jobs. Social sustainability, or providing fair and equitable working conditions, safe employees, and job security, must be incorporated into transport strategy for long-term well-being of operations. Labor and technology do not replace but are co-evolving capital. For competitive and robust auto logistics, investment in human and automation needs to be done at the same time [95, 96]**. Figure 4** illustrates that building a more resilient and sustainable automotive transportation system calls for a comprehensive, multi-layered strategy. Key priorities include strengthening logistics networks with built-in flexibility, shifting to cleaner and more efficient transport modes, upskilling the workforce to match evolving technological needs, and using digital tools to enable smarter, real-time coordination across the supply chain.

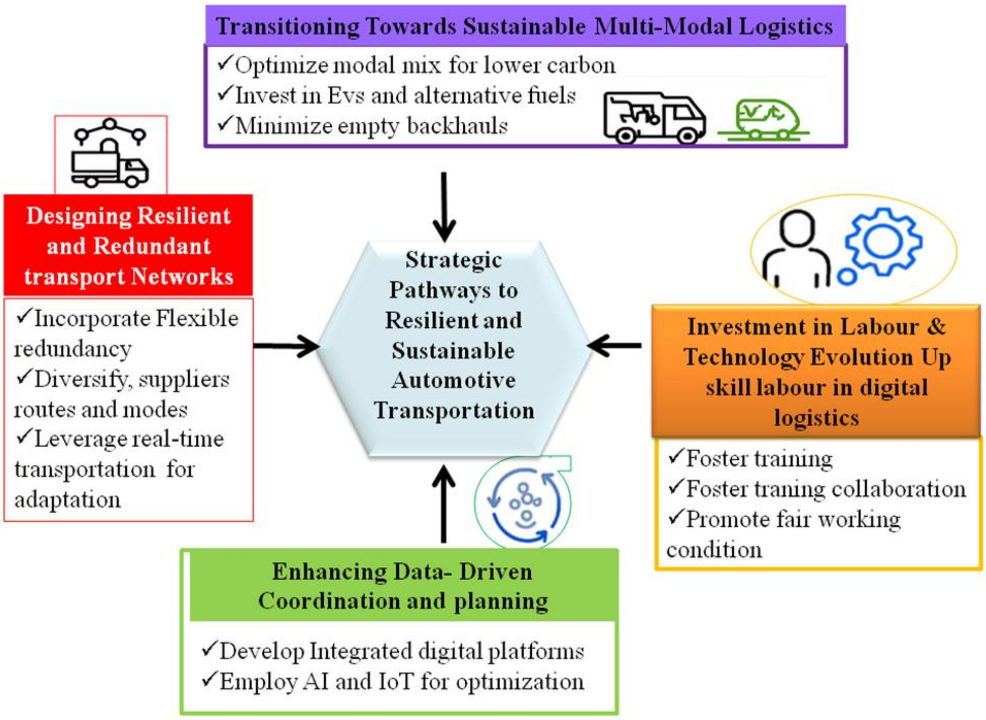

Figure 4. Strategic pathways for improving the resilience and sustainability of automotive transportation systems.

IV. Conclusion

Transportation in the automotive industry is not merely a logistics activity but a crucial element that drives operational efficiency, supply chain responsiveness, and long-term sustainability. This study has critically examined the current transport systems within the motor sector, highlighting key structural gaps that limit the industry's ability to address economic, environmental, and global challenges. The findings reveal that inefficiencies remain widespread across various stages of logistics, with issues such as low vehicle utilization and fragmented routing having a major impact, especially on cross-border and return transport operations. Although technologies like IoT, telematics, and transport management systems hold significant potential, their benefits are often limited by inconsistent adoption and poor system integration. Environmental challenges are further intensified by high carbon emissions, aging infrastructure, and inadequate regulatory support, all of which slow progress toward greener logistics. In addition, evolving transport policies and a shrinking pool of skilled workers have made the system more fragile, as clearly demonstrated during events like the COVID-19 pandemic and recent global supply chain disruptions. To overcome these challenges, the sector needs comprehensive, system-level transformation rather than gradual adjustments. Future research should focus on resilience modelling to predict and prevent disruptions, assess environmental impacts throughout the transport lifecycle, and better understand behavioral aspects influencing logistics decisions. Comparative policy studies across different regions and advancements in human–machine collaboration can also provide valuable insights. Such interdisciplinary approaches are essential to strengthen strategic planning, improve policymaking, and foster innovation in automotive logistics systems.

Abbreviation	Full Form
3PL	Third-Party Logistics
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AI-Optimized	Artificial Intelligence Optimized (Routing, Decision Making)
CO_2	Carbon Dioxide
COVID-19	Coronavirus Disease 2019
DC	Distribution Center
ERP	Enterprise Resource Planning
ETS	Emissions Trading System
EU	European Union
EV	Electric Vehicle
GHG	Greenhouse Gases
GPS	Global Positioning System

HFC	Hydrogen Fuel Cell
HR	Human Resources
ICT	Information and Communication Technology
IoT	Internet of Things
IRU	International Road Transport Union
JIS	Just-in-Sequence
JIT	Just-in-Time
KPI	Key Performance Indicator
km	Kilometer
LNG	Liquefied Natural Gas
OEM	Original Equipment Manufacturer
PDI	Pre-Delivery Inspection
R&D	Research and Development
RFID	Radio-Frequency Identification
SCM	Supply Chain Management
SME	Small and Medium-sized Enterprises
TMS	Transport Management System
USD / US$	United States Dollar
WEF	World Economic Forum
WMS	Warehouse Management System

Author Contributions:

Srinivasan Krishnan conducted the systematic analysis and drafted the manuscript and contributed to the editing of the manuscript. Rajan Chinna P supervised the project, provided critical revisions, and approved the final version for submission. All authors reviewed and approved the final manuscript.

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Declaration of interests

The authors declare that they have no conflict of interest.

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