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Digital technology diffusion through supply chain orchestration☆

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ABSTRACT

Digital technology diffusion is reshaping innovation across supply chain dynamics and ecosystem partners. Prior work often looks at one firm or uniform settings, missing how technology diffusion need to be orchestrated by ecosystem leader across diverse suppliers and other actors. To address this gap, this study employs an exploratory case study of the intelligent vehicle ecosystem, focusing on an original equipment manufacturer (OEM) and six supply chain partners. Although positioned in the supply chain, these actors influence the wider ecosystem thereby affecting technology diffusion beyond dyadic ties. Drawing on 35 interviews, observations, and secondary data, the research advances the technology diffusion and innovation ecosystem literatures in three ways. First, it highlights the evolving role of focal actor as ecosystem leader, demonstrating their progression from transformational to collaborative and ultimately empowering roles across different phases of digital technology diffusion. Second, it identifies three orchestration mechanisms, namely knowledge orchestration, incentive aligned orchestration, and market driven orchestration, and specifies when each should be deployed in response to partner-specific requirements. Third, it offers a novel perspective on how ecosystem leaders shift value propositions to include both core and peripheral partners. From a practical standpoint, the study offers OEMs actionable guidance to diagnose their diffusion context and select appropriate orchestration mechanism. It also provides policymakers with insights for designing targeted instruments that strengthen digital diffusion and support sustainable industrial growth.

1. Introduction

The rapid advancement of digital technology across industries has led to unprecedented innovation and transformation (Shen et al., 2024a). Unlike technological shifts that occurred incrementally, the current landscape is shaped by the concurrent development of multiple transformative digital technologies, including artificial intelligence, blockchain, autonomous driving systems, and Internet of Things (Han et al., 2024). This convergence presents considerable opportunities for value creation but also introduces notable challenges related to diffusion and scalability (Sjödin et al., 2022). Despite their potential, many emerging digital technologies fail to progress beyond the early pilot phases or encounter resistance during adoption (Ullah et al., 2021). A pertinent example is the autonomous vehicle sector. Although Tesla has obtained a permit to operate robotaxis in Texas, diffusion remains constrained by a fragmented regulatory ecosystem, including state-by-state permitting regimes, safety oversight mandates, ongoing federal investigations, and infrastructure gaps that restrict scaling beyond controlled zones (Veritis, 2025). Additionally, suppliers of critical components such as LiDAR and sensor technologies create integration hurdles, while the absence of smart traffic systems constrains functionality. Unclear legal frameworks further slow ecosystem-wide adoption. This gap between technological innovation and diffusion highlights the need to better understand the mechanisms facilitating or inhibiting large-scale digital technology adoption (Ullah et al., 2021).

The field of technology diffusion has long examined how innovations spread within and across organizations, industries, and societies (Geroski, 2000; Keller, 2004). Rooted in foundational theories such as Rogers (1962, 1995), this stream highlights factors influencing adoption, including organizational readiness, market conditions, and perceived benefits. Early models often depict diffusion as a linear process, with innovations gradually moving from early adopters to the

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broader market (Carlo et al., 2014) within homogeneous environments (Geroski, 2000; Comin and Mestieri, 2014). Yet the diffusion of contemporary digital technologies is more complex, often requiring coordinated action across entire supply chain (Spaniol and Rowland, 2022). Ecosystem-based diffusion reflects the need for synchronized efforts across interconnected actors rather than isolated adoption by individual firms (Carlo et al., 2014). The autonomous vehicle industry illustrates this phenomenon because adoption depends not only on original equipment manufacturer (OEM) readiness but also on the alignment of technology suppliers, infrastructure developers, policymakers, and consumers (Comin and Hobijn, 2010). Hence, it is important to understand digital technology diffusion as multi-phased, iterative processes across interdependent networks (Kouhizadeh et al., 2021; Rao and Kishore, 2010).

A second gap concerns limited understanding of orchestration mechanisms that facilitate supply chain wide diffusion. While studies such as Randhawa et al. (2024) and Abi Saad et al. (2024) acknowledge barriers to adoption, they provide insufficient insights into how focal actors synchronize diffusion among stakeholders. The strategies OEMs employ to align technological capabilities, coordinate engagement, and manage adoption remain underexplored (Pérez-Moure et al., 2023). Addressing these gaps requires examining how leaders or focal actors mobilize supply-chain partners, engage complementors, and mitigate resistance to accelerate adoption (Colovic et al., 2025). Without this perspective, diffusion risks being explained too narrowly as a matter of firm readiness, overlooking supply-chain actors' interactions that critically shape scaling.

The innovation ecosystem literature offers a suitable theoretical lens to address these gaps (Adner, 2017; Jacobides et al., 2018). Unlike traditional firm-level perspectives that treat diffusion as a matter of organizational readiness or market entry, the ecosystem view emphasizes the interdependence of multiple actors, and the orchestration needed to align them (Autio, 2022; Linde et al., 2021). Central to this literature is the concept of orchestration, where influential firms such as OEMs coordinate stakeholder interactions to drive transformative technology diffusion. Orchestrators strategically align technological goals, foster collaboration, and mitigate resistance, thereby creating conditions for alignment, scaling and institutionalization of value propositions (Foss et al., 2023). In practice, OEMs have to work with suppliers and technology providers to ensure interoperability, onboard new entrants to expand capabilities, and collaborate with platform developers to strengthen scalability (Tabas et al., 2023). They also engage policymakers to shape regulatory frameworks, for example by promoting sensor standardization or facilitating testing environments for smart vehicle systems (Appio et al., 2019). By integrating diverse supply chain actors, orchestrators help overcome fragmentation and enable diffusion processes that are otherwise constrained (Shen et al., 2024b). Framing this study through the innovation ecosystem lens thus highlights how OEMs employ orchestration strategies to address ecosystem-level barriers and accelerate diffusion within complex technological domains.

Against this backdrop, the objective of this study is *to explore the orchestration mechanisms employed by OEMs to facilitate the diffusion of digital technologies across supply chain and ecosystem partners*. We build on a unique dataset by employing a single case study-based approach and conducting thirty-five interviews with the OEM and six supply chain partners, including Tier 1, Tier 2 suppliers. This dataset offers an empirical perspective that responds to calls for more comprehensive, ecosystem-level analyses of diffusion processes (Randhawa et al., 2024; Abi Saad et al., 2024; Day et al., 2024). The findings highlight three orchestration mechanisms that collectively enable effective digital technology diffusion. Knowledge orchestration enhances partners' digital readiness through targeted upskilling, collaborative co-development, and shared infrastructure. Incentive aligned orchestration motivates partners to adopt and scale technologies by reducing financial risks, sharing IP benefits, and providing visibility and market access. Market driven orchestration creates demand pull by integrating user insights, shaping market perceptions, and influencing industry standards. This research contributes to both the digital technology diffusion (Reischauer et al., 2021; Vargo et al., 2020; Adner and Kapoor, 2016) and innovation ecosystem literatures (Adner, 2017; Jacobides et al., 2018). First, we show that ecosystem leaders adopt different roles that evolve as diffusion progresses. Second, we demonstrate when ecosystem leaders need to apply various orchestration mechanisms in response to partners' capability gaps, cost structures, and market conditions. Third, we highlight how the value propositions of technology diffusion expand over time, evolving from narrow engagements with a limited set of actors to broader collaborations that include both core and peripheral partners. The paper is structured as follows. In the next section, we review how the digital technology diffusion process has been discussed in the literature. Next, we discuss the role of focal actors during diffusion. The subsequent section outlines the research methods, followed by a presentation of the findings underpinning orchestration mechanisms. Finally, the discussion introduces the conceptual framework, present theoretical contributions and managerial implications. The paper ends by acknowledging limitations and outlining directions for future research.

2. Theoretical background

2.1. Digital technology diffusion process

Inter-firm technology diffusion refers to how innovations spread within and across industries over time, enabling their transition from invention to widespread application (Dahlke et al., 2024). Defined as the gradual acceptance and implementation of new technologies, diffusion translates research and development investments into practical outcomes (Hassan et al., 2024). For industrial firms, diffusion is critical for sustaining competitiveness, enhancing operational efficiency, and addressing evolving market demands (Ben Khalifa, 2022). It allows firms to modernize production processes and meet the expectations of increasingly sophisticated consumers (Ameye et al., 2023). In today's globalized and digitized economy, failing to diffuse advanced technologies risks fragmentation and stagnation, undermining long-term sustainability (Hassan et al., 2024).

Studies largely approached diffusion through linear models, most notably Rogers (1962, 1995), which describes adoption as a sequential process spreading from innovators and early adopters to the mainstream (Carlo et al., 2014). While foundational, this view has been argued for oversimplifying how technologies spread in practice. Dosi (1982), for instance, rejected one-directional “demand-pull” and “technology-push” accounts, instead framing technological change as a path-dependent and evolutionary process shaped by feedback between science, institutions, and markets. This perspective underscored that diffusion cannot be understood as a simple linear sequence but as the outcome of cumulative and selective interactions. Accordingly, scholars have advanced nonlinear perspectives. Kline and Rosenberg's (1986) chain-linked model emphasized feedback loops between research, development, and application, suggesting that diffusion progresses through iterative interactions rather than one-way sequences. More recently, modeling approaches have reinforced this systemic view. Wang et al. (2024) used multi-agent simulations to show how policy interventions and promotion strategies generate varied diffusion trajectories, while He et al. (2024) applied epidemic dynamics to knowledge diffusion, framing adoption as a contagion-like process that spreads unevenly through networks, accelerates through interactions, and slows once resistance or saturation emerges. These contributions highlight that diffusion is nonlinear, dynamic, and shaped by feedback among interconnected actors.

Scholars have also emphasized different stages and mechanisms within diffusion, though their perspectives remain fragmented. Fang et al. (2023) stress how early phases hinge on overcoming resistance and proving feasibility, whereas later phases require scaling and institutionalization. Palm (2022) highlights the role of innovation systems in bridging pilot projects with mainstream implementation, while Carter Jr et al. (2001) focus on how communication mechanisms evolve as technologies mature. Geroski (2000) and Comin and Hobijn (2010) similarly depict diffusion as progressing through waves of experimentation, scaling, and consolidation. Taken together, these contributions suggest that diffusion unfolds iteratively across interdependent stages, yet the literature treats each element in isolation. This fragmentation points to the need for more integrated perspectives that capture diffusion as a dynamic process shaped by multiple, overlapping mechanisms (Rauniar et al., 2024).

Prior research has identified several factors that influence these processes. Organizational readiness, including workforce competence, resources, and strategic alignment, plays a central role in enabling firms to absorb and apply new technologies (Al Hadwer et al., 2021). Market conditions such as customer demand, competitive intensity, and regulatory requirements also shape diffusion trajectories (Janssen et al., 2020). External drivers, including government incentives, institutional support, and industry standards, further accelerate uptake (Carter Jr et al., 2001; Palm, 2022). While these insights are valuable, they often frame diffusion mostly as a matter of firm-level adoption, underemphasizing the systemic interdependencies that condition large-scale technology deployment (Cho et al., 2023; Hassan et al., 2024; Truant et al., 2024).

The diffusion of digital technologies exemplifies this broader complexity. Digital technologies such as autonomous driving systems cannot scale through OEM readiness alone but require alignment with suppliers, infrastructure providers, and policymakers (Day et al., 2024). Systemic barriers include fragmented standards, integration challenges in LiDAR and sensor technologies, and the absence of interoperable infrastructure such as smart traffic systems (Jacobides et al., 2018; Reypens et al., 2021). Addressing these challenges requires coordinated efforts across supply chain ecosystems to establish standards, data-sharing platforms, and regulatory frameworks. Without such alignment, diffusion risks being delayed, fragmented, or failing outright (Abi Saad et al., 2024; Randhawa et al., 2024).

This recognition has increasingly turned attention to the mechanisms and role of focal actor in shaping diffusion trajectories. OEMs and other orchestrators are pivotal in aligning diverse stakeholders, fostering collaboration, and mitigating fragmentation (Park et al., 2019). By integrating suppliers, regulators, and complementors, they create the conditions for synchronized progress and large-scale diffusion (Anzivino et al., 2024; Linde et al., 2021). The following subsection examines these, outlining how focal actors contribute to digital technology diffusion.

2.2. Role of focal actor for technology diffusion

Innovation ecosystems provide a useful lens to explain how technologies diffuse across networks of interdependent actors, including suppliers, regulators, and complementors (Adner, 2017; Jacobides et al., 2018). Within this literature, focal actors such as OEMs are recognized as critical for bridging technological development and market scaling (Fredström et al., 2022). Prior research often conceptualizes orchestration as the positioning of firms within an ecosystem, understood as a network of roles and interdependencies that collectively deliver a value proposition (Adner, 2017). It also highlights how firms manage these interdependencies (Kolagar et al., 2022) and facilitate collaborative relationships (Abi Saad et al., 2024). Within this stream, the ecosystem-as-structure perspective is particularly relevant because it emphasizes how firms strategically navigate structural interdependencies and position themselves to guide the diffusion of complex innovations (Adner, 2017). This contrasts with other strands of innovation ecosystem research that primarily emphasize co-creation dynamics among diverse actors. These perspectives collectively underscore the importance of focal actors as ecosystem leaders, who must not only manage dependencies and mitigate risks but also strategically coordinate their roles to enable successful technology diffusion (Kolagar et al., 2022). Examining orchestration in this way is critical, since without attention to the mechanisms of alignment, leadership risks being treated as a predefined structural attribute rather than a set of adapted practices that actively drive diffusion (Pérez-Moure et al., 2023).

Here, it is useful to distinguish between innovation intermediaries and OEM orchestrators, as they embody fundamentally different forms of orchestration (Howells, 2006). Innovation intermediaries are typically neutral facilitators that bridge knowledge and capability gaps, acting as "system architects" who foster shared learning, knowledge access, and collaboration across diverse actors (De Silva et al., 2018). Their legitimacy stems from neutrality, adaptability, and the ability to strengthen long-term systemic capacity. Focal actors like OEMs, by contrast, orchestrate from a position of structural dominance, their role is less about impartial facilitation and more about embedding and disseminating specific digital technologies across their value chains of suppliers and customers (Colovic et al., 2025). This means that while intermediaries focus on ecosystem-level health and capability building (Spaniol and Rowland, 2022), OEMs direct and align ecosystems toward their innovative technological trajectories, leveraging platform control and market power to enforce alignment.

The challenge is further complicated by the dynamic nature of ecosystem leadership. Roles rarely remain static; instead, they shift depending on the uncertainties of diffusion and the evolving demands of stakeholders. Sometimes leadership involves building legitimacy, mobilizing commitment, or overcoming resistance (Kamalaldin et al., 2021), whereas in other moments it requires setting standards, ensuring interoperability, or engaging in regulatory advocacy and coalition building (Autio, 2022). Orchestration may equally involve rewarding adoption and stabilizing collective routines (Randhawa et al., 2024; Martin et al., 2024). Thus, in the case of OEMs, orchestration entails a deliberate steering of ecosystems, where selective partnerships, embedded standards, and mandated compliance distinguish their practices from those of traditional innovation intermediaries.

Finally, there is a need to better understand how focal actors being the ecosystem leaders combine mechanisms across different contexts of diffusion (Parida et al., 2019; Day et al., 2024) in collaboration with upstream suppliers, infrastructure providers, and downstream supply chain partners (Liu and Stephens, 2019). These gaps are particularly pronounced in industrial ecosystems, where the roles of orchestrators and other actors are diverse and interdependent (Fredström et al., 2022; Sjödin et al., 2022). As a result, while the importance of ecosystem leaders in diffusion is well acknowledged, the specific orchestration mechanisms they employ, the ways these mechanisms evolve, the roles they play, and the extent to which these roles need to shift remain insufficiently understood (Hurmelinna-Laukkanen et al., 2021). To shed light on these dynamics, we next outline the methodological choices that guide our empirical investigation of OEM-led ecosystems.

3. Methods

3.1. Study context and case selection

This study adopts an exploratory and single case study approach. The rationale for this approach is grounded in two distinct considerations (Bianchi et al., 2017; Eslami et al., 2023). First, digital technology diffusion within ecosystems is a multifaceted process that demands an in-depth understanding of interdependencies, interactions, and orchestration strategies. A single-case study provides the granularity required to unravel these complexities and address "how" and "why" questions, which are critical for theoretical and practical insights (Yin, 2009; Wang et al., 2024). Second, the digital technology diffusion in emerging industrial ecosystems requires communication with multiple ecosystem partners. A single-case study enables a thorough investigation, offering a foundation for future comparative studies (Liu et al., 2024).

The autonomous vehicle industry was chosen as the study context for three reasons. First, it exemplifies the intersection of advanced digital technologies and industrial complexity, integrating sensors, communication systems, and AI-driven software within a highly interdependent ecosystem (Su et al., 2023; Jacobides et al., 2016). Second, recent advances in autonomous driving and smart cabins, along with the entry of actors from diverse sectors such as cloud computing and digital services, demand extensive collaboration across suppliers and technology providers, making the industry a prime context for studying supply chain orchestration (Li et al., 2024; Kolagar et al., 2022). Finally, the industry faces sector-specific diffusion challenges, including regulatory hurdles, fragmented supply chains, and extended development cycles, highlighting the need for focused research (Xiong et al., 2022; Pérez-Moure et al., 2023).

In particular, this study focuses on Drive X, a Chinese German, joint-venture OEM renowned for its hybrid operational model that combines the agility of a startup with the stability of an established automotive company. Drive X exemplifies an ecosystem leader, like an OEM, in the autonomous vehicle ecosystem, actively integrating supply chain partners and fostering strategic partnerships in areas such as autonomous driving and smart cabin technologies. The selection of Drive X as the focal case was informed by a rigorous multi-step process. First, the OEM's industry position was evaluated based on factors such as market presence, innovation leadership, and ecosystem centrality. Second, Drive X demonstrated a strong strategic focus on digital technologies, prioritizing intelligence as a core objective and exhibiting collaborative leadership in its ecosystem. Finally, practical considerations, including data accessibility and willingness to participate, solidified Drive X as the ideal case for this research.

To complement the analysis of Drive X, six supply chain partners were selected based on their close collaboration with the OEM and active participation in digital technology initiatives (refer to Table 1). To contextualize the role of the six focal firms, it is important to distinguish their positioning within the automotive supply base. Tier 1 suppliers, as direct suppliers to the OEM, typically secure the most profitable contracts and are considered irreplaceable due to their provision of safety-critical and technologically complex components (Kazantsev et al., 2023). Tier 2 suppliers, by contrast, supply to Tier 1 entities, often focusing on more modular or commoditized components (Oyedijo et al., 2023). Within our study, Partners A, B, and C operate upstream, specializing in hardware and core software such as LiDAR systems, electronic controllers, and middleware (Alkhatib et al., 2019). Partners D, E, and F span both upstream digital provisioning (e.g., cloud infrastructure, AI/analytics pipelines) and downstream value creation (e.g., user-centric cockpit features, content services, and data-driven applications) (Scannell et al., 2000). Some of these firms are long-standing collaborators with Drive X, whereas others are recent entrants that introduce novel capabilities and contractual arrangements. Although we examine these actors as OEM suppliers, their roles extend beyond dyadic transactions: upstream partners influence sensing, compute, and integration standards, while downstream partners shape data flows, usage patterns, and service expectations that spread across the ecosystem.

Table 1
Details of the supply chain partners and other ecosystem partners.

Technology ecosystem partner	Company description	No. employees (+/−)	Role in the value chain
Partner A	An AI-driven robotics technology company focused on AI, chips, and hardware, providing products such as sensors and solutions for automotive and robotics. It is a global leader in intelligent LiDAR technology.	1400	Provides the core component for autonomous driving systems – the LiDAR system.
Partner B	A leading international mobility technology company specializing in the integration of smart cabin, driving, and Internet-connected services, developing integrated hardware and software algorithms.	8600	Provides electronic controller products, including controller hardware and the corresponding underlying software, and co-develops key technologies with Drive X for next generation autonomous driving controller programs.
Partner C	A platform software development company in the intelligent vehicle sector, focusing on middleware and foundational software development, offering scalable operating systems and customized solutions for autonomous driving.	70	Provides reliable communication middleware services, expanding its collaborative scope from traditional Microcontroller Unit (MCU) to System on Chip (SoC)-related middleware development.
Partner D	A cloud computing service provider owned by a leading global internet technology company, offering scalable and secure cloud computing services.	3200	Provides IT cloud computing services.
Partner E	A cloud service platform from an internationally renowned internet technology company, sharing its growth methodology and technical capabilities to help external businesses build digital capabilities and achieve sustainable growth.	270	Provides digital capabilities and collaborates on projects such as cabin large language models and chaos engineering.
Partner F	A globally leading internet technology company offering various services including communication, social media, gaming, cloud computing, advertising, and financial services.	10,800	Provides in-vehicle entertainment ecosystem products.

3.2. Data collection

Data were collected from both primary and secondary sources. We first reviewed industry materials such as white papers, government announcements, consultancy reports, company websites, public articles, annual reports, media coverage, podcasts, and academic studies to build a foundational understanding of the autonomous vehicle sector and Drive X. Primary data came from 35 semi-structured interviews conducted between May and November 2024. Respondents from Drive X included executives involved in supply chains and digital technology projects, while Partners A–F were represented by participants with close ties to Drive X and direct experience in joint initiatives on autonomous driving and smart cabins. Each interview lasted between 30 and 90 minutes as detailed in Table 2. We reached theoretical saturation at approximately 29 interviews. Although no new theoretical insights, themes, or activities emerged beyond this point, we coded all 35 interviews in recognition of the participants' contributions and the efforts of the data collection team. Moreover, consultation of secondary sources revealed no additional activities, further confirming that data collection

Table 2
Data source and coding category.

Data source	Details of the Interviewee(s)	Coding category	Duration (in minutes)
Primary data	Drive X: radar application development engineers (2), autonomous driving control algorithm engineers (2), autonomous driving platform software development specialists (2), autonomous driving functional safety development specialist (1), AI agent engineer (1), supplier quality engineer managers (2), senior managers of retail marketing (2).	IX	90, 73, 80, 54, 45, 52, 43, 42, 47, 60, 63, 64
	Partner A: radar systems engineers (2), senior perception algorithm engineer (1), autonomous driving simulation development engineer (1).	IA	32, 30, 42, 60
	Partner B: functional safety engineer (1), electronic hardware engineer (1), product manager (1), business planning managers (2).	IB	80, 32, 34, 31, 62
	Partner C: software engineers (2).	IC	40, 65
	Partner D: senior development engineer for database management control (1), cloud database product managers (2), senior specialist in business data analysis (1).	ID	70, 42, 45, 35
	Partner E: senior manager of customer service (1), marketing specialist (1), development engineer (1).	IE	80, 52, 50
	Partner F: senior key account sales managers (2), solution architect (1), senior ecosystem managers (2) in the automotive industry.	IF	90, 63, 66, 67, 30
	Walk-through observation	Visits	Number of Visits
	Attended the Drive X offline launch event, fan carnival, and conducted a visit to the user center.	VX	5
Secondary data	Types of documents	Reports	Number of copies
	Industrial level: Industrial white papers, government announcements, consultancy reports, and podcasts.	RI	125 copies
	Firm level: Podcasts, official websites, WeChat public articles, annual reports, media coverage, and academic research articles.	Reports	Number of copies
	Drive X	RX	53 copies
	Partner A-F	RA-F	189 copies

could be concluded.

The customized interview guide focused on understanding various mechanisms that the ecosystem leader follows to orchestrate with supply chain and other ecosystem partners for the purpose of technology diffusion (Gupta et al., 2024). For Drive X, the six key themes included: (i) whether digital technology diffusion is actively promoted and the motivations behind it; (ii) the primary drivers of digital technology diffusion; (iii) the key digital technologies currently being diffused through the ecosystem; (iv) incentives provided to partners to adopt these digital technologies; (v) various ways to diffuse digital technologies; and (vi) the impact of diffusion on Drive X and the broader ecosystem. For the supply chain partners, questions explored: (i) their role in the Drive X-led ecosystem; (ii) whether Drive X facilitates digital technology diffusion, and which digital technologies are involved; (iii) the incentives provided by Drive X; (iv) their digital technology-sharing practices with Drive X; and (v) the impact of this partnership.

Data were triangulated with secondary sources, including publicly available reports and documents, to validate and enrich the empirical findings. These measures ensured robust and comprehensive insights into digital technology diffusion within the Drive X ecosystem. For example, an informant from Drive X highlighted a strategic partnership with Partner E to co-develop an AI-driven personalized recommendation system, which significantly enhanced the user experience of the smart cockpit. To corroborate this, we examined Partner E's official website, which revealed that Partner E supported Drive X in gaining deeper insights into customer behavior, constructing detailed customer profiles, enabling personalized user interactions, and establishing a unified, user-centric data system. Further investigation on Drive X's website confirmed that its vehicles are equipped with a large AI model developed by Partner E, underscoring the depth of the collaboration. Additionally, an informant from Partner A indicated that Drive X collaborated with it to develop advanced environment perception algorithms utilizing LiDAR data. To validate this claim, we reviewed media reports, which revealed that Drive X and Partner A have engaged in extensive cooperation centered on an intelligent LiDAR system. This partnership has continuously strengthened Drive X's digital technical capabilities and expanded its applications in the field of intelligent assisted driving.

3.3. Data analysis

The data analysis followed a thematic approach, as outlined by Braun and Clarke (2006), to identify patterns in data while ensuring empirical accuracy. The process was carried out in six iterative phases: familiarization, initial coding, theme identification, theme review, refinement, and reporting (Panda et al., 2024; Quttainah et al., 2025). The data analysis was carried out using the NVivo software, which facilitated efficient management of codes, quotations, and data segments (Mortelmans, 2019). Initially, the research team familiarized themselves with the transcripts by reading and listening to recordings, capturing key segments and emerging ideas. The first stage of formal coding used open coding techniques, resulting in descriptive codes that reflected the raw data's essence. The first-order coding represented the various activities the ecosystem leader (the OEM) engages in with the supply chain and ecosystem partners. Examples include technical training programs and cross-functional knowledge sharing.

In the second stage, first-order codes were examined for patterns and grouped into second-order themes, which were reviewed for consistency and relevance. These themes represent various business practices, such as targeted upskilling and knowledge transfer. The second-order themes were subsequently combined into aggregate dimensions. In this study, the aggregate dimensions represent various orchestration mechanisms. Knowledge orchestration is such an example. We followed the Gioia methodology to visually present the data structure (Gioia et al., 2013; Haque et al., 2024).

As the study progressed, the analysis was iterative, evolving as new themes emerged, enabling a dynamic understanding of the subject. We mobilized the literature on digital technology diffusion and ecosystem orchestration (Abi Saad et al., 2024; Linde et al., 2021; Vargo et al., 2020) to ground our findings in theory and align them with empirical data. Multiple researchers ensured rigor, with discrepancies resolved through iterative discussion (Hamilton, 2020).

4. Findings

This section describes the findings (refer to Fig. 1) obtained from the informants on how various orchestration mechanisms were followed by the ecosystem leader (the OEM) for technology diffusion across supply chain partners and the ecosystem. Following the coding tree's order of aggregate dimensions, the findings of the study are presented below.

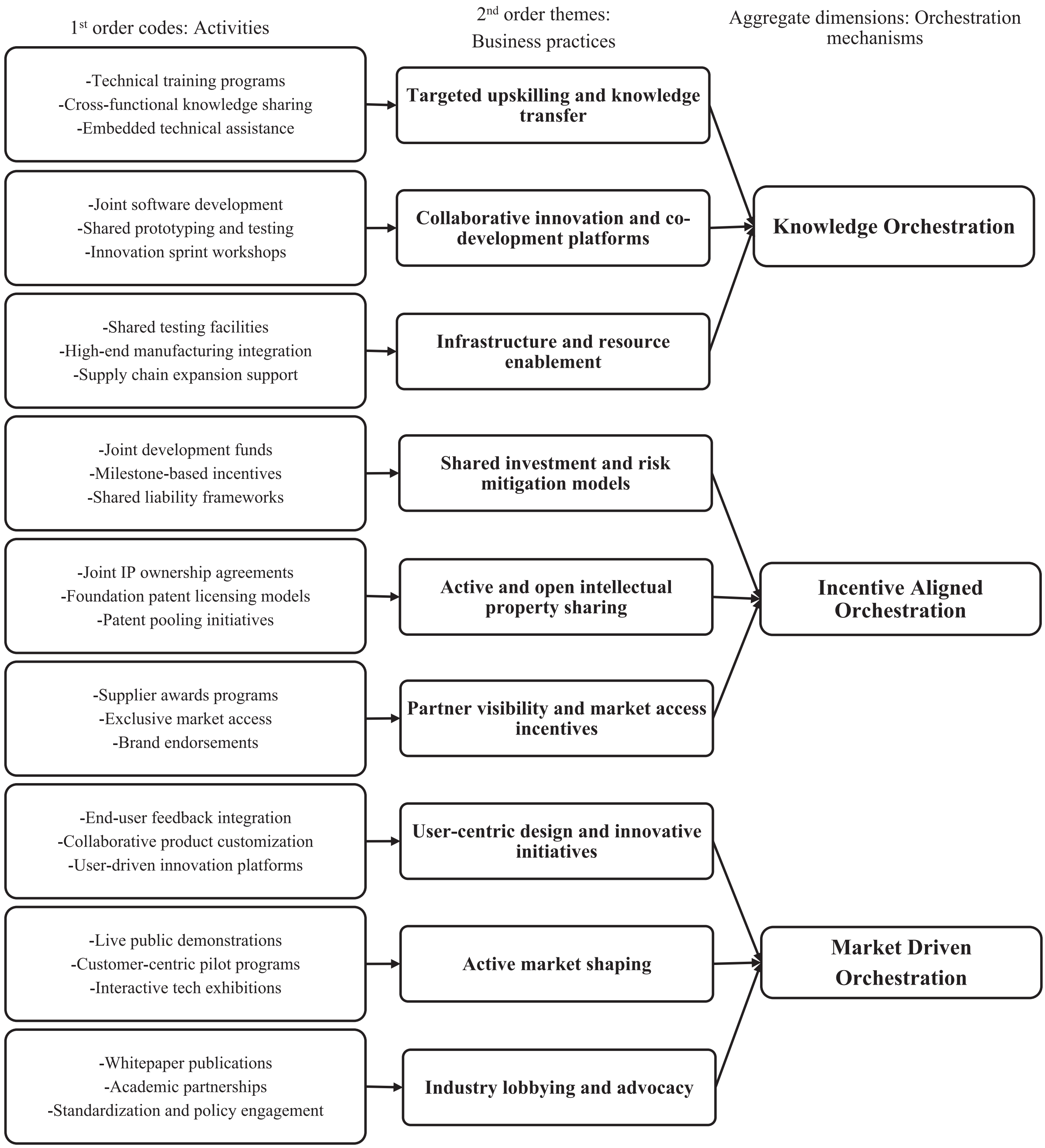

Fig. 1. Coding tree.

4.1. *Knowledge orchestration*

The first aggregate dimension, the knowledge orchestration mechanism, emphasizes enhancing the digital technological competencies and innovation capacities of ecosystem partners to enable efficient digital technology diffusion (Capestro et al., 2024). Through this mechanism, the ecosystem leader, Drive X, fosters digital technological readiness among partners by implementing tailored upskilling initiatives, collaborative innovation platforms, and infrastructural support mechanisms (Aagaard and Rezac, 2022). These practices collectively help bridge capability gaps and accelerate the adoption of transformative digital solutions within the supply chain (Annosi et al., 2021).

4.1.1. *Targeted upskilling and knowledge transfer*

To address gaps in technical expertise and facilitate the integration of digital technologies, Drive X prioritizes targeted learning programs and hands-on support for its partners. This practice is designed to empower ecosystem actors with the necessary skills and knowledge to align their operations with emerging technological standards, ultimately ensuring a cohesive and efficient digital technology diffusion process across the supply chain.

The first activity reported by respondents is the implementation of ***technical training programs***, where ecosystem leaders deliver workshops to strengthen partners' competencies. These upskilling initiatives provide hands-on experience with advanced digital technologies such as autonomous driving systems and smart cabins, covering areas like sensor calibration, software integration, and regulatory compliance. By enhancing practical capabilities and aligning with evolving standards, these programs reduce implementation challenges and enable smoother ecosystem-wide uptake. The autonomous driving functional safety development specialist from Drive X elaborated: *"During our previous thematic workshop with Partner A, we engaged in in-depth discussions regarding the failure scenarios of perception systems caused by calibration inaccuracies and other issues following the installation of LiDAR systems on vehicles. Through these technical exchanges, we successfully identified and recommended tailored improvement measures that specifically address their unique operational requirements and technical challenges."* (IX7).

Building on the foundational skills established through digital technical training, the second activity identified by respondents is ***cross-functional knowledge sharing***, which fosters continuous learning and exchanging best practices between Drive X's R&D teams and partners. As a progression from training, it promotes structured collaboration that bridges knowledge gaps. Focused sessions on user-experience design, data analytics, and cybersecurity enable partners to contribute directly to product development while aligning with Drive X's strategies, ensuring digital technological advancements are effectively implemented across the ecosystem. The senior key account sales manager from Partner F noted, *"Drive X engaged with us in a discussion on how to design personalized in-car entertainment interfaces to enhance user satisfaction. We explored the seamless integration of multimedia content such as audio, video, and games into the intelligent cockpit system. Additionally, we exchanged ideas on building a rich content ecosystem to offer users a diverse array of entertainment options."* (IF1).

Expanding on the drive created by knowledge sharing initiatives, the third activity reported by respondents was ***embedded technical assistance***, where Drive X deploys experts into partner firms to provide tailored, hands-on support. This immersive engagement helps partners integrate complex digital technologies into operations, optimize hardware–software interactions, and adapt solutions to their specific capabilities. By resolving technical issues on-site, this approach minimizes implementation risks. The autonomous driving control algorithm engineer from Drive X explained: *"Our division on autonomous driving has established a Product Technology Committee. This committee is tasked with formulating specific strategies to advance digital technologies and tailoring customized solutions for our partners. For instance, we have deployed engineering experts to Partner B to assist them in enhancing the real-time responsiveness of their controllers and the stability of their systems, thereby ensuring reliability in complex driving scenarios."* (IX3).

4.1.2. Collaborative innovation and co-development platforms

Advancing beyond foundational capability development, collaborative innovation and co-development platforms serve as a practice through which ecosystem leaders accelerate digital technology diffusion. Through joint research, iterative testing, and fast innovation cycles, partners evolve from passive recipients to active co-innovators, giving momentum to the spread of digital technologies within supply chains.

The first activity is ***joint software development***, where ecosystem leaders work directly with partners to design interoperable solutions aligned with supply chain operations. By embedding partner expertise early, this proactive co-development approach accelerates the diffusion of complex technologies, such as autonomous driving systems and smart cabin interfaces, by ensuring they meet both technical and market requirements. The senior perception algorithm engineer from Partner A stated: *"Drive X and we collaborated to develop environment perception algorithms based on LiDAR data, aiming to enhance the object detection and tracking capabilities of the autonomous driving system. Together, we worked on multi-sensor fusion algorithms that integrated LiDAR with cameras and other sensors to achieve more precise environmental perception."* (IA3).

The second activity is ***shared prototyping and testing***, which enables partners to refine and validate digital technologies in realistic environments. Access to shared platforms allows rapid feedback loops, ensuring that prototypes meet performance and safety standards while lowering integration risks. The autonomous driving platform software development specialist from Drive X explained: *"We collaborated with Partner D to deliver a cloud-based development platform that facilitated distributed team collaboration and code sharing. The platform integrated automated testing tools, enabling rapid validation and iterative optimization of software functionalities."* (IX5).

The third activity is ***innovation sprint workshops***, which bring together cross-functional teams for intensive, time-bound problem-solving. These workshops accelerate the transition from conceptualization to implementation by fostering creative solutions and collective ownership. The AI agent engineer from Drive X reflected: *"During a three-day workshop, we collaborated with Partner E to co-develop an AI-powered personalized recommendation system, significantly enhancing the user experience of the smart cockpit."* (IX8).

4.1.3. Infrastructure and resource enablement

Complementing capability enhancement and collaborative innovation, infrastructure and resource enablement is a vital mechanism for accelerating the diffusion of advanced digital technologies across ecosystems. By equipping partners with access to physical infrastructure and digital technological resources, ecosystem leaders remove bottlenecks and empower supply chain actors to scale and deploy cutting-edge solutions effectively. This practice ensures that innovations do not stall at the pilot stage but progress toward widespread implementation.

The first activity is ***shared testing facilities***, where ecosystem leaders provide partners with access to specialized laboratories and validation environments. Such facilities allow partners to rigorously test both hardware and software under simulated real-world conditions, ensuring compliance with safety and quality standards. This reduces product failure risks and shortens the cycle from prototype to deployment. The electronic hardware engineer from Partner B explained: *"Through Drive X's hardware-in-the-loop testing platform, we validated the real-time performance and reliability of the control algorithms, significantly enhancing the vehicle's control capabilities."* (IB2).

Building on validation, the second activity is ***high-end manufacturing integration***, granting partners access to advanced production technologies and established assembly lines. This enables scaling without the prohibitive costs of developing independent facilities. By embedding partners into existing workflows, leaders ensure quality consistency while accelerating production timelines. The radar systems engineer from Partner A stated: *"We utilized Drive X's manufacturing assembly line to swiftly integrate custom LiDAR units into the vehicles."* (IA2).

Progressing further, the third activity deals with ***supply chain expansion support***, where ecosystem leaders integrate partners into broader distribution networks and provide access to advanced management tools. This expands production capacities, optimizes logistics, and ensures timely delivery of critical components. The supplier quality engineer manager from Drive X elucidated: *"We introduced Partner B to other automotive manufacturing companies within the same corporate group, where shareholders have close equity ties, to help them expand the production scale of specialized electronic controllers."* (IX9).

4.2. Incentive aligned orchestration

The second aggregate dimension, incentive aligned orchestration, focuses on structuring financial and non-financial incentives to motivate ecosystem partners to adopt, develop, and scale digital technologies (Ge and Liu, 2022). Unlike knowledge orchestration, which builds partner competencies, incentive aligned orchestration creates the conditions for participation by reducing costs, mitigating risks, and providing economic or reputational benefits. This orchestration strategy is critical in complex ecosystems where the barriers to digital technology diffusion are often linked to resource constraints, uncertainty, and the misalignment of partner interests (Drori et al., 2024; Yeh and Chen, 2018). Drive X, as the ecosystem leader, applies incentive based practices that encourage partners to take active roles in innovation and integration. Through shared investments, intellectual property collaboration, and market visibility programs, Drive X aligns partner incentives with collective ecosystem objectives.

4.2.1. Shared investment and risk mitigation models

The first practice focuses on lowering financial and operational barriers that typically hinder digital technology adoption. By distributing risks and reducing upfront costs, Drive X creates conditions where ecosystem partners are more willing to invest time and resources in adopting complex digital technologies.

The first activity is the establishment of ***joint development funds***, where Drive X collaborates with partners to co-finance high-priority projects. These pooled funds lower financial barriers by distributing the cost of projects that involve advanced and uncertain technologies. Partners benefit by reducing their exposure to financial risks, while Drive X ensures commitment and collaboration in strategically important areas. The autonomous driving platform software development specialist from Drive X stated: *"We have jointly funded a development project with Partner D to create a cloud-based vehicle data management system. Our goal is to enable real-time collection, storage, and analysis of vehicle data through this system, thereby enhancing the functional experience of intelligent driving and smart cockpit features."* (IX5).

Building on this foundation, the second activity is ***milestone-based incentives***, which tie financial rewards to measurable progress in development and integration. This mechanism encourages partners to commit to project timelines and quality standards, ensuring that digital technology diffusion does not stall midway. It also keeps partner efforts aligned with agreed innovation outcomes. The senior ecosystem manager from Partner F stated: *"Drive X has provided us with a clear development framework and incentive mechanisms. Together with Drive X, we have established multiple milestones, including the design of the smart cockpit user interface and the implementation of voice recognition features."* (IF4).

The third activity is the design of ***shared liability frameworks***, where Drive X formalizes agreements to share the risks of potential failures during testing and deployment. This mechanism reduces partner reluctance to engage in experimental projects by creating a safety net. By ensuring that partners are not solely accountable for failures, the framework encourages them to explore high-risk, high-reward innovations. The autonomous driving functional safety development specialist from Drive X explained: *"We have signed a shared responsibility agreement with Partner A, clearly outlining the allocation of responsibilities in the event of LiDAR system failures during the testing period."* (IX7).

4.2.2. Active and open intellectual property sharing

The second practice centers on stimulating ongoing innovation and creating momentum for digital technology diffusion through intellectual property (IP) sharing. Traditional IP protection often creates barriers, limiting collaboration and slowing the spread of new technologies. By contrast, Drive X employs open and collaborative IP models that encourage partners to co-develop, customize, and scale innovations.

The first activity is the use of ***joint IP ownership agreements***, which ensure that digital technologies developed collaboratively are co-owned by Drive X and its partners. This shared ownership incentivizes both parties to invest in the long-term success of the innovation. The senior perception algorithm engineer from Partner A explained: *"Drive X and we have jointly developed a high-precision perception algorithm and entered into a joint intellectual property ownership agreement. According to the agreement, both we and Drive X co-own the patent for this algorithm."* (IA3).

Building on ownership, the second activity is ***foundation patent licensing models***, where foundational technologies are licensed openly to ecosystem partners under flexible terms. These models provide freedom for partners to customize and expand on the base technology while ensuring that Drive X and its co-developers benefit through tiered licensing fees. The autonomous driving control algorithm engineer from Drive X explained: *"We have collaborated with Partner C to develop an autonomous driving middleware that efficiently manages vehicle sensor data, computational resources, and communication modules. We have agreed to make these patents available under flexible licensing terms."* (IX3).

The third activity is the creation of ***patent pooling initiatives***, where Drive X consolidates critical patents with multiple partners into a shared repository. This provides affordable access, lowers entry barriers and accelerates collective scaling by giving partners shared resources that they can integrate into their own products. The autonomous driving platform software development specialist from Drive X stated: *"We have jointly established a patent repositories with Partners A, B, and C, which includes relevant patents in LiDAR perception technology, electronic controller optimization technology, and middleware task scheduling technology."* (IX5).

4.2.3. Partner visibility and market access incentives

The third practice focuses on empowering partners through recognition, visibility, and access to market opportunities. While financial and IP incentives create conditions for adoption and momentum, non-financial incentives strengthen long-term engagement and align partners with ecosystem goals by enhancing their reputational and commercial standing.

The first activity is ***supplier awards programs***, where Drive X recognizes and celebrates high-performing partners at prominent industry events. These awards not only highlight technological contributions but also raise partner credibility in the marketplace. Public recognition fosters pride and competition, motivating partners to invest further in innovation. The marketing specialist from Partner E remarked: *"At the annual technology conference, Drive X presented us with an award for digital innovation, recognizing our contribution in developing the personalized recommendation system."* (IE2).

Building on recognition, the second activity is ***exclusive market access***, which provides partners early opportunities to test and scale their solutions in emerging markets. By allowing partners access to pilot projects or fast-growing geographies, Drive X gives them a competitive advantage while simultaneously accelerating the diffusion of new digital technologies. The software engineer from Partner C emphasized the benefit: *"Drive X has granted us exclusive market access, allowing us early entry into its European market and participation in intelligent driving pilot projects."* (IC1).

The third activity is ***brand endorsements***, where Drive X co-brands products developed with partners. Co-branding enhances visibility, signals trust, and provides legitimacy for partner innovations in competitive markets. It also reinforces the identity of the ecosystem as a whole. The AI agent engineer from Drive X explained: *"We have collaborated with Partner F to develop an intelligent cockpit entertainment system that integrates high-definition displays, voice control, and personalized content recommendation features."* (IX8).

4.3. Market driven orchestration

The third aggregate dimension, market driven orchestration, focuses on generating market pull for digital technologies through user engagement, market influence, and industry advocacy (Kazantsev et al., 2023; Liu et al., 2022). While knowledge orchestration equips partners with competencies and incentive aligned orchestration motivates participation through rewards, this orchestration addresses the market-side conditions that determine whether digital technologies are truly absorbed at scale. This mechanism recognizes that even well-developed and incentivized innovations can stall if there is insufficient demand, limited consumer confidence, or fragmented regulatory environments (Kumar et al., 2024).

Drive X, as the ecosystem leader, pursues market driven orchestration by integrating user perspectives, shaping market awareness, and steering industry standards. By proactively aligning digital technological innovation with market needs, Drive X reduces barriers to acceptance and accelerates diffusion across the intelligent vehicle ecosystem (Sjödin et al., 2022). The following three practices demonstrate how Drive X creates pull forces that complement internal capabilities and incentives, ensuring that digital technologies are not only developed but also widely adopted.

4.3.1. User-centric design and innovative initiatives

The first practice, user-centric design and innovative initiatives, centers on embedding consumer voices into the development process to ensure that innovations address genuine market needs. Whereas knowledge- and incentive-based mechanisms operate primarily within the supply chain, this practice extends orchestration outward by treating consumers as active participants rather than passive recipients. Through systematic engagement, Drive X ensures that new technologies resonate with end-user expectations, which reduces resistance and accelerates diffusion.

The first activity, ***end-user feedback integration***, involves collecting and analyzing insights from consumers throughout the product lifecycle. Drive X channels this feedback to ecosystem partners to refine features, improve usability, and address potential shortcomings prior to commercial release. This proactive loop closes the gap between technical development and market acceptance. The senior manager of retail marketing from Drive X explained: *"We gathered user feedback through various channels, including in-car systems, mobile applications, and customer service centers, with a particular focus on the usability, functional practicality, and performance of the smart cockpit system."* (IX11). By responding directly to consumer experiences, Drive X ensures that partners develop products that are trusted and readily accepted in the market.

Building on user insight, the second activity, ***collaborative product customization***, adapts digital technologies to regional market contexts. Drive X participates with suppliers and digital partners for tailoring autonomous driving and smart cabin solutions to local regulatory conditions, cultural preferences, and environmental factors. This flexibility strengthens product–market fit and accelerates uptake across diverse markets. A senior ecosystem manager from Partner F explained: *"Drive X validated how we analyzed consumer preferences and discovered a high demand for personalized content recommendations and voice control features. Based on these findings, we optimized the recommendation algorithms and voice control modules."* (IF4).

The third activity, ***user-driven innovation platforms***, extends participation by inviting consumers to contribute directly to idea generation through interactive platforms. This goes beyond feedback and customization to co-creation, where users actively shape product trajectories. By cultivating this participatory culture, Drive X transforms consumers into advocates, creating organic demand that accelerates diffusion. A manager from Partner E shared: *"On Drive X's platform, we invited users to contribute ideas for improving the smart cockpit system and suggesting new features. For instance, users proposed innovative suggestions such as emotional recognition capabilities for the intelligent voice assistant."* (IE1).

4.3.2. Active market shaping

The second practice, active market shaping, moves beyond consumer engagement to influence broader perceptions and reduce market uncertainty. Advanced digital technologies often face skepticism regarding safety, reliability, and value. To counter these challenges, Drive X organizes high-visibility initiatives that build legitimacy, generate excitement, and normalize adoption.

The first activity, ***live public demonstrations***, provides experiential proof of new technologies. By showcasing autonomous driving features and smart cabin functionalities in real-world settings, Drive X reduces consumer skepticism and reassures regulators and partners about performance reliability. The senior manager of retail marketing from Drive X explained: *"We collaborated with Partner A to organize an autonomous vehicle showcase event, demonstrating a variety of features including automatic lane changing and pedestrian recognition."* (IX12). These events foster credibility by making digital technologies tangible.

The second activity, ***customer-centric pilot programs***, allows selected users to test new technologies in controlled yet realistic conditions before commercial release. This deepens engagement and transforms early adopters into advocates who share their experiences publicly, thereby accelerating broader acceptance. A senior sales manager from Partner F recalled: *"We jointly designed a pilot program with Drive X, inviting consumers to participate in testing. We provided technical support and data analysis tools to ensure efficient collection and analysis of user feedback."* (IF1). Pilots not only validate readiness but also serve as social proof, reinforcing confidence in large-scale diffusion.

The third activity, ***interactive tech exhibitions***, creates immersive environments where industry professionals and consumers engage directly with innovations. Unlike demonstrations and pilots, which focus on credibility and trust, exhibitions build momentum by positioning digital technologies as part of an inevitable future. These forums generate anticipation and highlight ecosystem-wide progress. As one senior manager from Drive X explained: *"We collaborated with Partner E to organize an interactive technology exhibition, featuring live demonstrations of the smart cockpit system, technical presentations, and interactive experience zones."* (IX11).

4.3.3. Industry lobbying and advocacy

The third practice, industry lobbying and advocacy, complements user engagement and market shaping by addressing systemic enablers of diffusion. While consumers and markets generate demand, industry standards and regulations determine whether digital technologies can scale consistently across geographies. Drive X plays a central role in shaping these conditions by engaging in thought leadership, partnerships, and policy development.

The first activity, ***whitepaper publications***, involves Drive X and partners co-authoring research that highlights emerging trends, technical best practices, and safety benchmarks. These publications inform industry discourse, guide stakeholders, and reduce uncertainty. The autonomous driving functional safety development specialist from Drive X mentioned: *"We jointly released a white paper with Partner D on industry trends in smart vehicle technology, covering aspects such as smart vehicle testing and standard specifications."* (IX7). By setting narratives early, Drive X builds legitimacy and consensus around its digital technological approaches.

The second activity, ***academic partnerships***, fosters knowledge creation and diffusion through collaborations with universities and research institutes. By engaging in joint research projects, co-developing emerging technologies, and contributing to scholarly publications, Drive X helps ensure that new scientific and technical insights circulate within the academic community and beyond. These collaborations enable the OEM to advance foundational knowledge while supporting broader dissemination through education, conferences, and open research outputs. As one engineer from Partner A explained: *"Through Drive X, we are collaborating with leading universities to jointly develop innovative autonomous driving perception technologies, with a focus on deep learning-based LiDAR object detection algorithms."* (IA3). Such partnerships empower industry-wide innovation by embedding ecosystem advances in shared research communities.

The third activity, ***standardization and policy engagement***, targets regulatory institutions and industry consortia to codify rules that enable interoperability and compliance. By participating in standard-setting bodies, Drive X ensures its digital technologies are not only technically robust but also legally recognized. A Drive X engineer explained: *"We have joined the AUTOSAR alliance together with Partner C, contributing to the development of safety and interoperability standards for middleware, ensuring seamless integration of hardware and software from different manufacturers."* (IX3).

The supply chain partner wise mapping for various orchestration mechanisms is presented in Table 3.

Table 3
Supply chain partner wise mapping for orchestration mechanisms.

Aggregate dimensions	Second-order codes	First-order codes	A	B	C	D	E	F
	Targeted upskilling and knowledge transfer	Technical training programs	+	−				+
		Cross-functional knowledge sharing						+
		Embedded technical assistance		+		−		+
	Collaborative innovation and co-development platforms	Joint software development	+	+				−
		Shared prototyping and testing	−			+	+	
Knowledge Orchestration		Innovation sprint workshops						+
	Infrastructure and resource enablement	Shared testing facilities		+		−		
		High-end manufacturing integration	+	+	−			
		Supply chain expansion support		+				
	Shared investment and risk mitigation models	Joint development funds				+		
		Milestone-based incentives	−					+
		Shared liability frameworks	+			+		
	Active and open intellectual property sharing	Joint IP ownership agreements	+					
Incentive Aligned Orchestration		Foundation patent licensing models			+			
		Patent pooling initiatives	+	+	+	−		
	Partner visibility and market access incentives	Supplier awards programs						+
		Exclusive market access			+	−		
		Brand endorsements						+
	User-centric design and innovative initiatives	End-user feedback integration	+			−		
		Collaborative product customization		+				+
		User-driven innovation platforms	−					+
		Live public demonstrations	+				−	
		Customer-centric pilot programs						+
		Interactive tech exhibitions					+	−
	Active market shaping							
		Whitepaper publications				+	−	
Market Driven Orchestration		Academic partnerships	+		+			
	Industry lobbying and advocacy	Standardization and policy engagement			+	−		

Note: "+" indicates the activity was present, "-" indicates the activity was informed as absent, and blank spaces indicate activity could have been present or absent, though not concludable with available data.

5. Discussion and implications

This section introduces a structured framework (refer to Fig. 2) derived from the empirical findings regarding how digital technology diffusion happens through three orchestration mechanisms. These mechanisms address distinct yet interconnected facets of digital technology diffusion within an industrial ecosystem (Linde et al., 2021). The findings revealed that technology diffusion does not only unfold as a

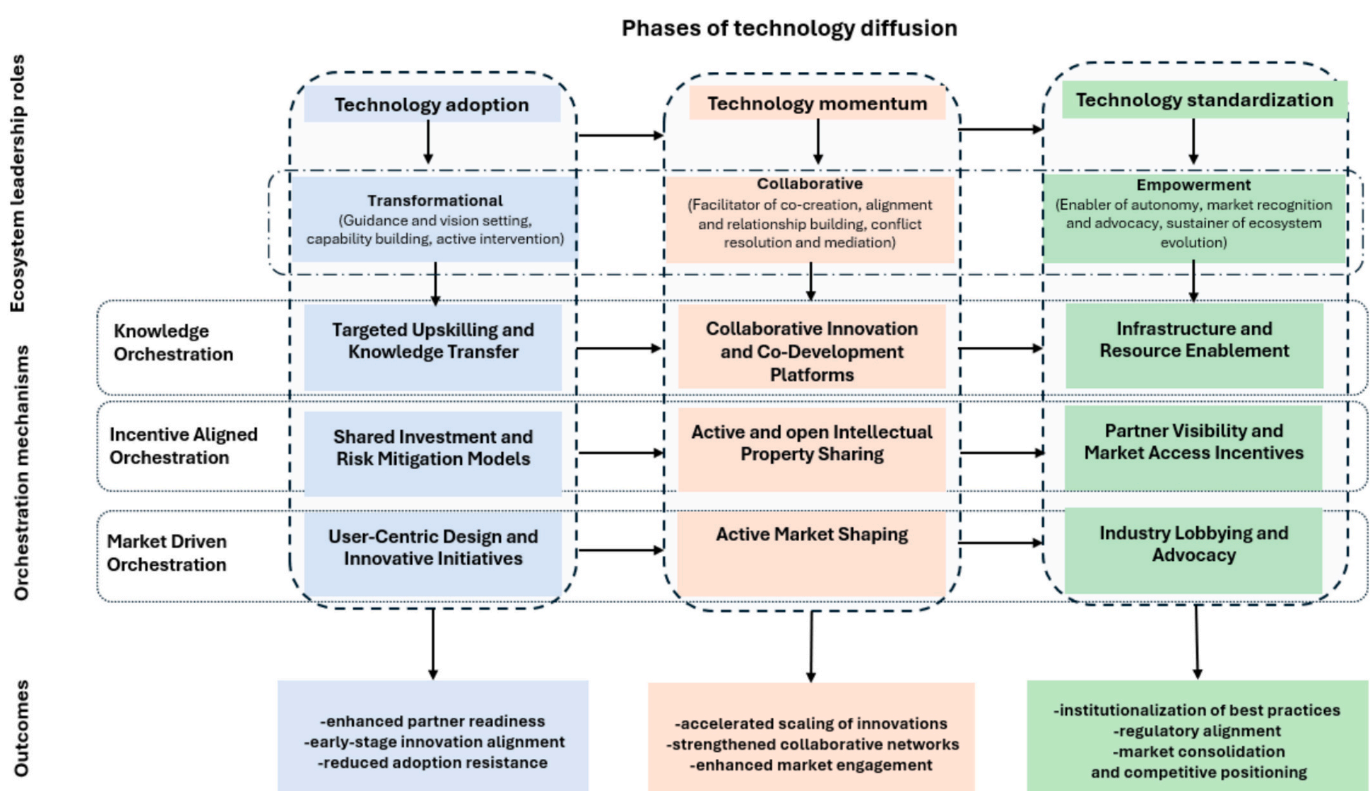

Fig. 2. Framework.

simultaneous event but also progressively where the role of ecosystem leadership shifts. To capture this progression, our framework integrates two pivotal variables: **phases of digital technology diffusion** and **roles of the ecosystem leader**. By mapping orchestration mechanisms across different supply chain partners (see Table 3), we also gain a conceptualization of the orchestrator's role and how it evolves within the ecosystem. By role, *we mean the capacity of a focal actor to guide, influence, and coordinate participants in order to achieve shared goals and drive collective innovation* (Foss et al., 2023). The identification of phases is based on how respondents described the temporal unfolding of activities. Supply chain partners consistently distinguished between practices experienced at the beginning of their collaboration and those that became prominent at later stages. Importantly, this reconstruction is validated by both long-term and new partners: long-term partners confirmed that they had previously undergone the very activities newer partners are experiencing today, thereby, reinforcing the phased character of diffusion practices.

The first phase, namely ***technology adoption***, marks the initiation of digital technology diffusion, emphasizing the foundational integration of innovations within ecosystem partners' operations (Alkhatib et al., 2019). Here, the focal actor directs enablement actions (for example, training, embedded assistance, risk sharing) to actively drive change by equipping partners with essential skills, resources, and confidence and thus takes transformational role. This phase is characterized by direct interventions to lower barriers and reduce uncertainties surrounding new technologies. Practices such as targeted training build technological readiness under knowledge orchestration, while joint investments and milestone-based incentives reduce financial risks under incentive aligned orchestration. Similarly, user-centric design ensures that innovations are tailored to consumer needs under market driven orchestration (Sjödin et al., 2022). These interventions generate trust and legitimacy, lowering resistance to emerging solutions. For instance, targeted workshops with Partner A addressed sensor calibration issues in LiDAR systems, building hands-on competence, while co-investments with Partner D on a cloud-based data management system alleviated funding pressures and accelerated early engagement. As outcomes, this phase enhances partner readiness, creates early-stage alignment, and reduces adoption resistance, laying the foundation for subsequent diffusion activities (Gomes et al., 2021).

The second phase, ***technology momentum***, focuses on scaling innovations through fostering iterative improvements, and expanding ecosystem collaboration. The empirical findings suggest that ecosystem leader adopts orchestrating practices that leverage collective intelligence rather than unilateral intervention, which we named as collaborative role. Collaborative innovation platforms under knowledge orchestration enable partners to co-develop complex technologies through shared prototyping and iterative testing (Mann et al., 2022). At the same time, open intellectual property sharing under incentive aligned orchestration distributes knowledge and rewards, incentivizing collective advancement (Aagaard and Rezac, 2022). Market shaping initiatives under market driven orchestration, such as live demonstrations and pilot programs, build consumer trust and generate visibility (Fang et al., 2023). This role is fundamentally different from the initial phase because the emphasis shifts from equipping partners to sustaining their active involvement in innovation. Empirical illustrations include Drive X's collaboration with Partner A to co-develop multi-sensor fusion algorithms that enhanced object detection, and with Partner E to design a personalized recommendation system through rapid prototyping workshops. Together, these practices accelerate scaling within ecosystem by strengthen partner interdependencies, and deepen market engagement, giving digital technologies the momentum needed for diffusion.

Finally, the ***technology standardization*** phase secures the institutionalization and widespread diffusion of digital technologies by embedding them into industry structures and regulatory frameworks. Here, the ecosystem leader found to adopt an empowering role, focusing on enabling partner independence, promoting recognition, and ensuring regulatory alignment. Knowledge orchestration facilitates shared testing facilities and advanced manufacturing integration, providing partners with the infrastructure to sustain innovation beyond pilot projects (Azzam et al., 2017). Incentive aligned orchestration evolves into recognition-based mechanisms such as market access programs and collaborative branding, which empower partners by enhancing their visibility and credibility (Shen et al., 2024b). Market driven orchestration takes the form of industry lobbying and standardization initiatives that align digital technologies with safety norms and interoperability standards. Unlike the collaborative role of the previous phase, the empowering role focuses less on joint development and more on creating conditions that allow partners to independently scale and sustain innovations. For example, Drive X's introduction of Partner B to expanded supply chain networks facilitated the mass production of electronic controllers, while participation in the AUTOSAR alliance with Partner C advanced interoperability and compliance. These outcomes consolidate ecosystem-wide capabilities, institutionalize best practices, and secure long-term sustainability of diffusion through regulatory and market alignment across the industry.

5.1. Theoretical implications

First, *this study highlights the evolving and dynamic role of ecosystem leaders in the diffusion of digital technology*. We introduce three distinct roles, *transformational, collaborative, and empowering*, that ecosystem leaders must adopt to ensure successful diffusion. In the transformational role, leaders take a front-facing position, driving technological readiness by equipping partners with essential resources and aligning them with strategic goals. As the diffusion process matures, leaders transition to a collaborative role, fostering co-development and ensuring alignment among ecosystem actors. Finally, in the empowering role, leaders step back to facilitate the self-sustained scaling of digital technologies across the ecosystem. This adaptive role transition is critical for long-term diffusion success, as a rigid leadership approach may hinder partners' willingness to engage, adapt, and innovate (Pérez-Moure et al., 2023). If ecosystem leaders fail to adjust their roles over time, partners may resist adoption due to concerns about overdependence, lack of autonomy, or misalignment with their strategic objectives (Sjödin et al., 2022). Furthermore, without role adaptation, leaders risk losing their ability to effectively manage evolving technological and regulatory landscapes, which can create diffusion bottlenecks and competitive disadvantages (Hurmelinna-Laukkanen et al., 2021). Importantly, our findings show that the effectiveness of each role remains consistent across all of the orchestration mechanisms, whether applied individually or in combination, enabling leaders to tailor engagement to contextual needs (Kazantsev et al., 2023).

Thus, we extend the *technology diffusion literature* (Reischauer et al., 2021; Vargo et al., 2020; Adner and Kapoor, 2016), which primarily portrays ecosystem leaders as static facilitators or intermediaries (Autio, 2022; Colovic et al., 2025). By theorizing leadership as adaptive and evolving, we contribute a more dynamic understanding of ecosystem orchestration, particularly in complex settings such as the autonomous vehicle industry, where technological, regulatory, and market conditions are constantly shifting (Abi Saad et al., 2024; Randhawa et al., 2024).

Second, this study identifies three distinct orchestration mechanisms, knowledge, incentive-aligned, and market-driven, based on partner-specific requirements. Knowledge orchestration is essential when supply chain partners lack capabilities to engage with digital technologies, requiring OEMs to provide upskilling initiatives, embedded technical assistance, and co-development workshops. However, a leadership-driven knowledge approach does not always suffice. In our empirical context, Drive X rolled out a collaborative perception module for autonomous driving without accounting for Partner A's limited experience in multi-vehicle communication. Partner A struggled to implement the system independently and postponed adoption, creating delays in the broader ecosystem rollout. In such cases, other mechanisms become decisive. Incentive-aligned orchestration is critical when suppliers face high upfront costs and technological risks. For instance, Tier 1 suppliers of LiDAR systems expressed reluctance to bear the costs of calibration failures; in response, Drive X co-financed development and signed shared responsibility agreements to reduce perceived risk. Similarly, cloud-based data management platforms developed with Partner D relied on milestone-based funding to align investments with performance goals. Market-driven orchestration, in turn, addresses adoption challenges stemming from regulatory uncertainty or weak end-user demand. Concerns about consumer acceptance of autonomous features and fragmented standards led Drive X to organize live demonstrations with Partner A, launch pilot programs with early users alongside Partner F, and participate in standardization initiatives such as AUTOSAR with Partner C to establish interoperability benchmarks. These actions not only legitimized the digital technologies externally but also reassured partners of future scalability.

Our findings thus reveal that while OEMs remain responsible for orchestrating diffusion, supply chain partners actively shape which mechanism becomes most decisive. Partners' capability gaps, cost structures, and market exposure push OEMs to recalibrate their orchestration practices across knowledge, incentive, and market domains (Howells, 2006). This partner-driven perspective explains why OEMs cannot rely on a single mechanism. Unlike innovation intermediaries, who act as neutral facilitators of resource and knowledge flows (De Silva et al., 2018), OEMs face direct pressures from supply chain actors embedded in tightly coupled product architectures and regulatory environments (Colovic et al., 2025). Their orchestration therefore extends beyond enabling learning to continuously adjusting incentives and demand-shaping interventions in response to bottlenecks (Randhawa et al., 2024).

Thus, we extend the *technology diffusion literature* (Chen et al., 2021; Rogers, 1995; Rogers, 1962), which often portrays diffusion as a firm-level process dependent on organizational readiness or innovation attributes (Mousavi et al., 2023). Our findings show that in complex digital domains, diffusion instead relies on interactive coordination across upstream and downstream suppliers and ecosystem partners (Abi Saad et al., 2024). By distinguishing between knowledge, incentive-aligned, and market-driven orchestration, we demonstrate how OEMs must not only create the foundation for diffusion but also adapt their orchestration in response to partner-specific pressures.

Finally, *this study shows how value propositions expand , evolving from narrow engagements with a limited set of actors to broad collaborations that include both core and peripheral partners.* OEMs not only occupy structural positions but also dynamically orchestrate partners around shifting value propositions that co-evolve with the diffusion process (Zeng et al., 2021). In the adoption phase, value propositions are relatively narrow, emphasizing risk mitigation and capability building to lower uncertainty for closely aligned partners through targeted resources, training, and strategic alignment (Randhawa et al., 2024). As diffusion gains momentum, value propositions expand toward collaborative innovation and knowledge sharing, mobilizing a broader set of actors and fostering co-development to ensure interoperability across complementary equipment and applications (Pérez-Moure et al., 2023). In the standardization phase, value propositions broaden further toward industry-wide legitimacy, regulatory compliance, and compatibility across heterogeneous actors. At this point, OEMs shift from direct control to creating enabling conditions that allow partners to scale digital technologies independently within shared standards and frameworks by supporting regulatory dialogues, contributing to standard-setting initiatives, and institutionalizing practices that reduce uncertainty and enhance alignment across supply chains and markets (Abi Saad et al., 2024).

This contribution extends the *innovation ecosystem literature* (Adner, 2017; Jacobides et al., 2018), particularly the ecosystem-as-structure perspective, which emphasizes how firms strategically navigate interdependencies to guide the diffusion of complex innovations but often treats value propositions as a fixed logic. In contrast, we demonstrate that value propositions are evolutionary, expanding in scope and inclusiveness as diffusion progresses, and that ecosystem leaders must continually match evolving value propositions with shifting actor requirements to drive industry-level transformation (Sjödin et al., 2022; Kolagar et al., 2022).

5.2. Managerial implications

This study presents three managerial implications. Firstly, strategic decision makers and managers leading digitalization initiatives must strategically identify and engage supply-chain and ecosystem partners capable of driving technology diffusion. By understanding the diverse roles of partners and effectively applying orchestration mechanisms, ecosystem leaders can accelerate the adoption of advanced technologies. Knowledge orchestration enables leaders to enhance partners' technical competencies through targeted training and resource access, ensuring that partners are equipped to adopt complex digital solutions. For instance, Siemens supports SMEs in adopting industrial IoT solutions by providing specialized training and shared technological resources, fostering smoother technology integration. Incentive aligned orchestration allows leaders to align economic interests by sharing investment risks and offering financial incentives, encouraging sustained partner engagement in innovation. A prime example is Tesla's co-investment in gigafactories with Panasonic, which not only shares the financial burden but also strengthens joint efforts in battery technology development (Perkins and Murmann, 2018). Similarly, market driven orchestration helps ecosystem leaders create market pull by engaging end users and stakeholders through public demonstrations and interactive platforms, much like how Amazon Web Services (AWS) hosts innovation challenges to accelerate the adoption of its cloud services across industries (Borra, 2024). Secondly, firms offering similar products or services can also learn how to align with OEM-led digital diffusion strategies by engaging in collaborative innovation, co-investing in joint projects, and participating in market shaping activities. Companies, such as Bosch, invest heavily in autonomous driving R&D and collaborate closely with OEMs, such as Volkswagen, to ensure their sensor technologies are seamlessly integrated into next-generation vehicles (Brenner and Herrmann, 2018).

Finally, policymakers can leverage these insights to design targeted policies and funding programs that support ecosystem leaders and partners in orchestrating digital technology diffusion. By recognizing the critical role of capability building, governments can fund digital upskilling programs for SMEs, similar to the European Union's Horizon 2020 initiative, which helps SMEs collaborate with large firms on advanced technologies, such as AI and IoT. In addition, policymakers can introduce tax incentives or grants to encourage joint R&D and infrastructure development, as seen in South Korea's co-funding of semiconductor projects between Samsung and its supply chain partners to bolster national competitiveness (Kim and Seong, 2010). Furthermore, supporting industry-wide standardization efforts is essential for streamlining digital technology diffusion. The U.S. National Institute of Standards and Technology (NIST) exemplifies this approach by working with industries to develop cybersecurity and interoperability standards for autonomous vehicles, reducing regulatory barriers and facilitating market entry (Taeihagh and Lim, 2019). By implementing such supportive frameworks, policymakers can directly enable and accelerate the diffusion of digital technologies across ecosystems, fostering sustainable industrial growth and technological advancement.

6. Limitations and future scope

This study provides insights into digital technology diffusion through ecosystem orchestration but has several limitations that open avenues for future research. First, the focus on a single OEM and six ecosystem partners in the autonomous vehicle industry limits the generalizability of the findings. Future studies could extend this analysis to multiple OEMs and partners across different industries, where ecosystem structures and market conditions vary significantly. Factors such as regulatory requirements, technological complexity, and the degree of partner interdependence may shape how orchestration mechanisms operate. Second, while this study included partners from different sectors, it did not explore how diffusion mechanisms might differ when partners share similar knowledge bases, technological capabilities, or organizational practices. Future research could compare contexts where partners are closely aligned versus highly diverse to better understand diffusion challenges.

Third, the qualitative nature of this study limits the ability to test the observed relationships statistically. Future studies could develop and validate quantitative models to assess how orchestration mechanisms affect technology adoption, momentum, and standardization. Finally, supply chain partners can be added, removed, or replaced, meaning orchestration mechanisms may not be applied uniformly and can move beyond the suggested orchestration mechanisms. Future research should examine how the orchestration mechanisms as well as three roles highlighted in this study can be adapted or customized to suit both new entrants and long-term partners.

CRediT authorship contribution statement

Lei Shen: Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Conceptualization. **Qingyue Shi:** Writing – original draft, Methodology, Data curation, Conceptualization. **Debadrita Panda:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis, Data curation, Conceptualization. **Vinit Parida:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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