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The roadmap towards a Software Defined Vehicle UK centric platform: A systems thinking approach

UK economic opportunities arising from disruption in the automotive sector

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April 2026

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Executive Summary

Problem statement

The UK automotive ecosystem lacks a shared and operational understanding of what is a software-defined vehicle (SDV). Although OEMs, suppliers, and technology firms increasingly reference SDVs, the term is used inconsistently, often referring to isolated technologies such as operating systems, high-performance computing (HPCs), or advanced driver assistance systems or (ADAS) rather than the full system of stakeholders and capabilities required to deliver an SDV global competitive advantage. This perspective creates misalignment across supply chains, slows integration of new technologies, weakens investors' confidence, limits policy and regulation development, and confuses end users' trust in these new emerging technologies. These challenges lead to a key questions for progressing the UK ecosystem that we address in this report:

What is the complete system of stakeholders and capabilities needed to build end-to-end SDV capability? For each stakeholder to realise new revenue streams, what capabilities do they need? What partners do each need? How will cost structures and business models shift? How do incumbent and new entrants need to adapt to one another and the regulatory environment?

Approach

Firstly, we evaluate the evidence on the existing SDV ecosystem and the challenges it is facing peeling back the layers of hype to identify tangible evidence of the challenges in the industry. Alongside this we delve into historical examples of successful technology ecosystems. This enables us to identify the attributes of relevance to grow global competitive advantage in a new technology sector, especially one that's integrated to an existing safety-critical supply chain. The report then applies a systems thinking approach to map the full sociotechnical landscape required for SDV deployment. This includes clearly defining responsibilities and interactions of SDVs ecosystem stakeholders, then explicitly listing their assumptions, and monitoring their validity across the entire SDV lifecycle.

Two complementary control structures were developed: one representing the pre-deployment phase covering R&D system design, software development, data governance, interface specification, safety and cybersecurity assurance, and compliance, and a second representing post-deployment operations, including real-world data flows, OTA updates, claims, and continuous assurance.

Key findings

National advantage in an emerging technology sector rarely stands alone. Wide scale technology shifts must work in tandem with existing, competitive manufacturing and services bases. Matching the right blend of public-private investment at the appropriate stage of the development cycle is an important consideration.
To facilitate the interface challenges identified at a technical level and to promote the right kind of 'blended investment' we find in the evidence base that open platforms and digital ecosystems have become key lever for scaling emerging technologies. This addresses the identified challenges of 'reorganisation' required within the SDV context among diverse stakeholders, including incumbents, new entrants, adjacent general-purpose technologies, finance, insurance, data, maintenance and ultimately the user/ consumers, to realise a globally competitive position.

Building on this the systems thinking findings show that SDV development is reshaping power dynamics across OEMs, suppliers, cloud providers, and software platform companies. However, several systemic challenges hinder progress: mismatched engineering cultures between automotive and software industries, difficulties implementing CI/CD pipelines in a safety-critical environment, increased safety and cybersecurity risks from OTA updates, shifting insurance liability from drivers to systems and growing dependence on end-user approved data sharing. The systems thinking approach reveals that SDV deployment cannot be understood through the SDV alone but must be treated as a continuous socio-technical system involving technical, commercial, regulatory, and end-user customers. A shared open platform is essential to coordinate stakeholders, standardised interfaces, enable trusted data exchange, support continuous assurance, and reduce integration barriers. Historical evidence shows that successful platforms in a manufacturing and safety-critical value chain context balance openness with control, rely on strong orchestrators, and require governance structures that build trust and manage risk.

Key recommended actions

The report recommends establishing a UK- centric open SDV platform built on shared requirements, standardised interfaces, and continuous assurance. First, comprehensive requirements register should be created to capture functional safety, cybersecurity, data governance, interoperability, commercial, and user trust needs. The platform should adopt common data models and open interfaces to ensure reusability across vehicles and fleets. Assurance data models and open interfaces to ensure reusability across vehicles and fleets.

Assurance must be treated as a continuous lifecycle activity, supported by real-time monitoring, incident reports, and operational feedback. A controlled certification and onboarding process is needed for third-party services accessing vehicle data. Public trust must be embedded through transparency about data use and its impact on services such as insurance and battery health. The UK should also invest in SDV-specific skills development across engineering, regulation, insurance, fleet operations, and public sector decision-making, while accelerating capability transfer from adjacent sectors such as AI, cloud computing, cybersecurity, telecommunications, and digital health.

Glossary

Term	Definition
ASIL	Automotive Safety Integrity Level; a risk classification used in ISO 26262 to define the required level of risk reduction for safety-related functions.
AUTOSAR Classic	An automotive software platform mainly used for deeply embedded, real-time ECU functions.
Business Model Canvas (BMC)	A structured framework used to describe how an organisation or ecosystem creates, delivers, and captures value.
Central compute / HPC	A high-performance computing platform in the vehicle that consolidates processing tasks previously distributed across multiple ECUs.
Chiplet	Chiplet – A small piece of silicon, typically just a few millimetres to about 2 centimetres per side and thinner than a human hair (roughly 50–100 micrometres thick), that performs one part of a chip's job—like processing or memory. Several chiplets are packaged together, connected by tiny wires spaced closer than a grain of sand, to form one complete, larger chip.
Chiplet-based automotive	An automotive compute architecture that uses multiple smaller semiconductor dies, or chiplets, integrated into a single package to support scalable and specialised processing.
Chiplet-centric architecture	An architecture where system design is organised around modular chiplet integration rather than a single monolithic semiconductor device.
Control action	An instruction, decision, rule, or intervention issued by one actor to influence another.
Control structure	A systems thinking representation of the actors, feedback loops, control actions, and responsibilities that influence system behaviour.
Data governance	The policies, responsibilities, and controls that define how data is collected, accessed, shared, protected, and used.
Data standardisation	The use of common data formats, interfaces, and semantics to enable interoperability between stakeholders and systems.
E/E architecture	The electrical and electronic architecture of a vehicle, including ECUs, wiring, communication networks, sensors, actuators, and compute platforms.
ECU	Electronic Control Unit; an embedded controller responsible for managing specific vehicle functions, such as braking, powertrain, body control, or infotainment.
Feedback loop	A mechanism through which information about system behaviour is returned to decision-makers or controllers to support adjustment or control.
Heterogeneous chiplets	A hardware platform combining different processing units, such as CPUs, GPUs, NPUs, DSPs, FPGAs, and safety processors, to support varied workloads.
Heterogeneous hardware	A hardware platform combining different processing units, such as CPUs, GPUs, NPUs, DSPs, FPGAs, and safety processors, to support varied workloads.
ISO 26262	The automotive functional safety standard for electrical and electronic systems in road vehicles.
Leading indicators	Early signals or measurable factors that suggest whether a system, project, or ecosystem is moving towards a desired outcome before final results are visible.

Middleware	Software that provides communication, abstraction, and service management between applications, operating systems, and vehicle hardware.
OTA update	Over-the-air update; a remote software update delivered to a vehicle without requiring a workshop visit.
RISC-V	An open-standard instruction set architecture used to design processors and processor cores.
ROS	Robot Operating System; a set of software libraries and tools used to build robotic and autonomous systems.
ROS heritage	The influence of ROS concepts, tools, middleware patterns, and modular software design on autonomous driving software stacks such as Autoware.
Safe Linux	Use of Linux-based platforms in systems where safety-related requirements must be addressed through additional processes, evidence, monitoring, isolation, or certification strategies.
Service-Oriented Architecture (SOA)	A software architecture where vehicle capabilities are exposed as reusable services that can be accessed by different applications.
Software headroom	The remaining compute, memory, storage, network, or timing capacity available to support future software functions, updates, or performance growth.
SOTIF	Safety of the Intended Functionality; safety concerns related to performance limitations, functional insufficiencies, or reasonably foreseeable misuse when the system is not necessarily malfunctioning.
V2X	Vehicle-to-everything communication, including vehicle-to-vehicle, vehicle-to-infrastructure, vehicle-to-network, and vehicle-to-pedestrian communication.

Introduction

Opportunity of the software defined vehicle motivating the research

The term ‘Software Defined Vehicle’ (SDV) is becoming increasingly discussed in the automotive space. Emerging through a sectoral need to understand where the automotive and mobility opportunities are in emerging technology capabilities, such as AI and computation. However, given the hype around emerging technologies, it’s not always clear what SDV means. We see instances of emerging capabilities in the automotive supply chain being referred to as SDV’s, such as operating systems. Original Vehicle Manufacturers (OEM’s) refer to future vehicle releases as being software defined. Emerging technologies such as self-driving and advanced driving assistance system (ADAS) rely heavily on state-of-the-art software and hardware. However, a precise understanding of the software defined vehicle ecosystem, its stakeholders and their associated capabilities is missing.

As a result, when taking the abstract concept of the SDV to a concrete implementation level, we see challenges emerging. Traditional automotive players can be out of sync with new supply chain entrants, slowing down integration to their existing product lines. Investors are unable to build robust certainty around new revenue streams, holding back investment. Policy makers lack the data to design enabling policy interventions. Manufacturers are unable to make ‘build or buy’ decisions for new components. This all leads to the promise of new mobility products and services being constrained, and end users become confused about true capabilities and limitations of technology.

Providing a detailed and comprehensive ‘map’ would provide detailed insight that would help long-term decision-making across all these stakeholders. What is the complete system of stakeholders and capabilities needed to build end-to-end SDV capability? For each stakeholder to realise new revenue streams, what capabilities do they need? What partners do each need? How will cost structures and business models shift? How do incumbent and new entrants need to adapt to one another and the regulatory environment?

This research work takes a systems thinking approach to both create this map and secondly go on to demonstrate how it can be used as a tool for analysis of individual stakeholders’ capabilities and risks, as well as at a system level to inform national level policy making and investment. It concludes with a set of requirements needed to build a platform that will address gaps and risks in the entire system, making recommendations for private investment and Government policy. Concluding with the key attributes for a UK roadmap that leads to being globally competitive and integrated.

The research has been undertaken by the Safe Autonomy Research Group at WMG, The University of Warwick in partnership with the Centre for Sectoral Economic Performance at Imperial College London. The systems thinking methodologies applied have been developed through several years of research at WMG, with applications in technology spaces such as self-driving (El Badaoui *et al*., 2026) (Khastgir *et al*., 2021) and vertical take-off and landing (VTOL) (Elizebeth *et al*., 2025) where a similar need from technology developers, policy makers and other key stakeholders has emerged to understand their ‘systems context’ in new ways.

This work builds on the previous report by Centre for Sectoral Economic Performance at Imperial College London *‘Opportunities arising from disruption in the automotive sector: A UK perspective’* which identified how global forces, technology disruption, climate imperatives, shifting geopolitics and rapidly evolving consumer expectations are reshaping the automotive and mobility competitive landscape faster than at any point in the past century. Against this backdrop, the emergence of the Software-Defined Vehicle (SDV) was identified not simply as an evolution of today’s electric or connected vehicles, but as a fundamental rearchitecting of the automotive value chain. Identifying alignment with core UK strengths, the report concludes that ‘the UK could take the lead in developing a software-defined vehicle (SDV) ecosystem …. With a key suggestion from this preliminary work to consider the implementation of collaborative platform initiatives to address the competitiveness of the UK automotive sector in an ecosystem approach. These programmes would address core automotive system components, core development processes, and the impact on waste, health and usage behaviour to build products and services that are globally competitive. Universities, fleet operators, automotive OEMs, suppliers and government agencies should be considered key stakeholders. These recommendations form the foundation of this follow-on research.

Exploring salient factors throughout the SDV narrative, the report makes clear that the UK is not yet structurally prepared to seize this opportunity due to fragmented capabilities, slow transformation, supply chain vulnerability and deindustrialisation risks. A recurring finding was that many UK strengths, AI research, autonomy leadership, chip design, cloud services, and advanced engineering, operate in silos.

Research question and approach

In response, where the original report identified what needs attention, this work asks how the UK can practically organise itself to respond to the opportunities arising from SDV's, asking the question:

"For the UK to exploit the opportunities of the software-defined vehicle, what are the requirements of an SDV innovation platform specifically and what complete system of stakeholders, capabilities and interactions will it need to enable?"

To address this question, the research begins (Section 1) by reviewing the research evidence on SDVs and the practical bottlenecks being faced across the industry. We define an SDV as 'a vehicle whose engineering and operations are centralised through software across both safety-critical and non-safety-critical attributes: the software first vehicle'. We consider SDV complexity across supply chains and stakeholders, including components (i.e. silicon to systems), integration (i.e. Continuous Integration [CI]/ Continuous development [CD] pipelines), realising safety-criticality, insurance, data sharing and skills. This is with the aim of illuminating the complex chain of capabilities and technology needed to realise new business models. Reflecting the first section, and with the aim of enhancing integration through this complex chain, we conclude by looking at existing efforts to develop an SDV open platform.

Section two of the report presents the methodology and findings from three interrelated streams of work:

- Section 2a considers the existing evidence on what conditions enable countries or regions to develop, scale, and sustain global leadership in new technology or sub-technology domains? This analysis places an emphasis on well-designed open platforms. This leads us to comparatively explore these attributes in greater depth, considering what can be learned from historic use cases, such as the Rolls-Royce' power-by-the-hour' service orientated supply chain integration approach, enabled by technology. An emphasis on safety-critical supply chains is undertaken, looking at platforms as both technology platforms, governance platforms, and ecosystem platforms.
- Section 2b moves on to organise these prior findings in a meaningful way that will lead us to actionable research findings. We present our systems thinking methodology to then develop a structured systems thinking approach to mapping the SDV ecosystem that can identify not only hazards and risks, but also dependencies, gaps, weak signals, and growth opportunities across the SDV ecosystem. This provides three systems-thinking models of the SDV. The first through the development stage, recognising that product development programmes in automotive are years in length and billions of dollars in value. The second looks at a restructuring (and with a slightly different set of stakeholders) when moving into the commercialisation and operation stage. The final model focuses on the highly technical set of stakeholders underpinning the SDV Operating System itself.
- Section 2c finally validates the value of the model through organising and analysis of the resulting data around the nine building blocks of the business model canvas (BMC) to describe how an organisation/ ecosystem/ supply chain creates, delivers, and captures value in an innovation. This is achieved through application to three stakeholders 'Case Study 1: Battery Health, Charging, and Lifecycle Value Management', 'Case Study 2: Secure Software Platform Integration and Update Assurance', and 'Case Study 3: SDV-insurance pricing case study'

We conclude in section 3 by extracting the central findings on what is required to build an enabling open platform to build stakeholder wide capability in the UK. We organise the findings into a road map and set of recommendations. This will act as a signpost for manufacturers, technology developers, product and service designers and policy makers as to the roles they could effectively take to build a successful system of sectoral economic performance in the automotive sector. Also, providing a set of next steps for this work itself.

Section 1: Evidence on the challenges of realising the SDV vision

Defining the Software-Defined Vehicle

From the technical literature, a software-defined vehicle (SDV) is not a single technology but a convergence of architecture, lifecycle/ business model, and security/ safety perspectives.

SDVs open up new product and service potential. For example, for automated driving assistance systems (ADAS) and self-driving, SDV architectures enable required continuous development and deployment of perception models and services, orchestrated across vehicle and backend systems, with hardware specific variants and automated rollback (Weiss et al., 2025). They also open up potential in cooperative planning scenarios, such as coordinated lane merging between an ambulance and a private vehicle, where strict timing guarantees for vehicle-to-everything (V2X) messages are required to maintain safety (Teixeira et al., 2024).

In the realm of adaptive and personalised services, SDV literature describes the potential for automatic configuration of vehicles to occupants' characteristics, including coordination with healthcare provider registries and adaptive cabin functions (seating, music, climate, lighting) based on user profiles (Teixeira et al., 2024). Trust frameworks for selfdriving vehicles similarly envision customisable cabins for work, leisure, and accessibility, and rich interfaces between SDVs and external road users (Kuru, 2022).

Operational benefits in fleet management and maintenance, especially beneficial for logistics and public transport, are also advanced through SDV architectures. Research surveys highlight opportunities for predictive maintenance, warranty optimisation, and fleet services based on continuous data collection from SDV platforms (De Vincensi et al., 2024). Continuous over the air (OTA) and V2X capabilities also underpin fleet management, vehicle sharing, and mobility as a service (MaaS), enabling remote configuration, feature gating, and dynamic optimisation over large vehicle populations (Weiss et al., 2025; De Vincensi et al., 2024; Liu et al., 2022; Narashiman et al., 2024).

From an architecturecentric view, SDVs are vehicles built around centralised or zonal E/E architectures, highperformance computing platforms, and standardised, service-oriented software stacks, with full overtheair (OTA) update capability (Jiang, 2024; Pan et al., 2024; Teixeira et al., 2024). Functions are implemented as software services running on shared compute rather than on many isolated ECUs.

From a lifecycle and businessmodel view, SDVs are platforms whose value is defined by continuous software evolution, datadriven services, and "vehicles as updatable products" over 10–15 years (Liu et al., 2022; Shao et al., 2022; Khamis & Goswami, 2025; Ohlsen, 2022). The vehicle is treated as a longlived, networked product that can change role and capability through software.

From a security and privacy view, SDVs are "invehicle solutions" that abstract hardware via software, are mandatorily connected to the cloud, and support OTA as a firstclass mechanism, which creates new cyber and privacy attack surfaces spanning invehicle, edge, and cloud systems (De Vincensi et al., 2024).

Recent systematic work attempts to unify these fragmented definitions, deriving industryoriented SDV definitions that emphasise softwarerealised functionality, hardware abstraction, connectivity, and integration into wider mobility/data ecosystems (Máté et al., 2025; Khamis & Goswami, 2025; Jiang, 2024).

In fact, Balint Mate et al (2025) find there is a divergence in conceptualising what an SDV is, especially between research and industry stakeholders. We therefore define our own definition of a SDV for the purpose of this report, drawing on established definitions from the industrial literature (Eclipse Foundation, Advanced Propulsion Centre, IBM, Siemens and ARM (Otto, Wlcek and Wortmann, 2025):

A vehicle whose engineering and operations are centralised through software across both safety-critical and non-safety-critical attributes: the software first vehicle

Although many of the service level use cases are increasingly discussed in the literature, they are tightly anchored in the architectural and tooling capabilities that permeate deeply into the system engineering of the vehicle, and secondly, are largely based on conception or experimental ideas that are yet to be proven at scale. This identifies a key challenge in bringing the entire value chain to commercial realisation. Further analysis of the stakeholders is required, in which we must remember the benefits (and resulting stakeholders) are both in new products/ services and in enhanced engineering and manufacturing approaches, as shown in Figure 1. Furthermore, it remains unclear whether specific service offerings can be innovated on by individual parties (as we often see in the mobile app industry) or if engineering and commercial realities dictate the groupings of new product and service offerings around fundamental technology and engineering shifts. We will systematically review the literature to further understand the nature and characteristics of these challenges.

Software Defined Vehicle opportunities

Engineering/ manufacturing
Reduce cost/time to market

For example:
- Reduce development cycle/ hardware abstraction in S/W
- Integration/efficiency enabling more capability at reduced cost
- Circular/ reuse/ extended life of H/W
- Reduced hardware (embedded electronics i.e. ECU, ethernet, etc)
- Component upgrades (vs model upgrades)

Product/ service
Flexibility

For example:
- AV/ ADAS/ DCAS enhancer
- Remote driving enhancer
- Data monetisation enhancer
- Safety and security enhancer
- Service/ product updates/ release enhancer
- Component upgrades enhancer (i.e. sensors)

Figure 1: Software-defined vehicle opportunities across engineering and manufacturing benefits, and product and service opportunities.

The multi-stakeholder challenge across SDV attributes

Analyses of the evidence on SDV ecosystems emphasise shifting power and roles among OEMs, Tier1 suppliers, ICT/cloud providers, and new software platform players (Liu et al., 2022; Shao et al., 2022; Ohlsen, 2022). As software and services become the main differentiators, control of operating systems, data platforms, and user experience becomes central. These 'power' structures and their shifting nature under conditions of technology transition are essential context in which to analyse the industry.

Traditional OEM–Tier1 relationships, optimised for hardware centric products and slow-release cycles, often struggle to adapt. Capability gaps in software, data, and DevOps, along with fragmented toolchains and certification frameworks, are repeatedly cited as obstacles (Khamis & Goswami, 2025; Liu et al., 2022; Ohlsen, 2022).

Some areas of analysis describe a move toward "coopetition" among OEMs, Tier1s, ICT/cloud giants, semiconductor firms, and platform providers (Liu et al., 2022; Shao et al., 2022; Ohlsen, 2022). Each actor seeks a favourable position in the emerging SDV ecosystem while being compelled to collaborate on shared infrastructure, standards, and safety.

Some manufacturers pursue verticalisation strategies, investing in inhouse operating systems, cloud stacks, and even silicon to retain control and capture more value (Khamis & Goswami, 2025; Shao et al., 2022). Others lean heavily on third-party platforms, trading control for speed and economies of scale (Jiang, 2024; Ohlsen, 2022). Chiplet ecosystems can be seen as a way to balance custom differentiation with shared components and supplychain resilience (Narashiman et al., 2024).

Systemintegrator and "software factory" perspectives see integrators as orchestrators of cloud, tooling, and OTA operations across multiple OEMs and suppliers (Weiss et al., 2025; Ohlsen, 2022). They aggregate complexity, enabling smaller players to participate in SDV ecosystems without building full stacks themselves. Showing that orchestrators could well hold a pivotal place in the re-structuring of ecosystems. Especially where software products and services become a significant proportion of the 'value' interface with users.

There is a rich set of data on the nuanced technical and engineering challenges faced across the value chain of SDV stakeholders. Too many to cover within this report. However, it's essential that we paint a picture of this context, with a few diverse examples explored below.

- **System and Architecture CoDesign (silicon-to-system):** Work on chipletbased automotive compute highlights the need to combine heterogeneous chiplets, CPUs, GPUs, accelerators, memory and I/O, under strict constraints of cost, thermal performance, reliability, and safety (Narashiman et al., 2024). These decisions shape what services can realistically run over the vehicle's life and are a concrete example of how novel service offerings and their requirements ripple down the systems-engineering pipeline, often with multiple hand-offs between supply chain partners. Such as silicon vendors, Tier1 compute suppliers, OEM system architects, and safety teams who must negotiate tradeoffs between future software headroom, BOM cost, and certification complexity.

- **Continuous Integration/Continuous Development (CI/CD) Pipelines:** These pipelines automate builds, tests, and deployments across vehicle, edge, and backend targets, integrate AI model development, and use an OTA middleware to manage rollouts and rollbacks (Weiss et al., 2025). Whilst CI/CD methods and tools are well established across software development industries, adaptation to SDV specifically raises challenges that include ensuring safety when updates affect distributed components, integrating regulatory and regional constraints into deployment logic, and coordinating multiple organisations' codebases and toolchains. OEM softwarefactory teams, Tier1 software houses, AI developers, and cloud operators must work within a shared process while still respecting organisational boundaries (Weiss et al., 2025; Khamis & Goswami, 2025; Ohlsen, 2022).

- **Prioritising safety/ security critical performance:** In a software-defined vehicle (SDV), safety and security functions such as braking, steering, and automated driving coexist with infotainment, personalisation, and third-party services on a highly connected, updateable platform (Jiang, 2024; Teixeira et al., 2024; Pan et al., 2024). The fact that SDVs are expected to host outsourced applications and continuous OTA updates while still satisfying safety regulations makes this separation an architectural requirement rather than an optional feature (Sghaier et al., 2025; De Vincensi et al., 2024). Approaches include physical separation via HPC's and dedicated chip sets (Narashiman et al., 2024; Teixeira et al., 2024), software engineered solutions such as central computers with strict virtualisation and service-oriented architectures, where separation is primarily logical and enforced by hypervisors and middleware (Pan et al., 2024; Teixeira et al., 2024), and governance solutions where technical separation must be accompanied by clear allocation of responsibilities, liabilities, and performance indicators among manufacturers, infrastructure operators, and regulators if trust is to be maintained throughout the SDV lifecycle (Kuru, 2022).

- **Insurance liability and risk:** Shift from driver to system/ manufacturer makes traditional driver-centric risk models inadequate; insurers must consider system capabilities, software, and human–machine interaction. Multi-party liability and burden of proof (driver vs OEM vs software supplier) complicate the ability to effectively manage risk. Along with the potential for new risks, such system flaws, software updates, communication failures, and cyber-attacks which add unfamiliar, evolving risk vectors. Work is required to explore solutions such as moving to proactive, telematics and MLbased risk assessment, including anomaly detection and splitting between human vs technology risks. With unequal or restricted data access across the ecosystem threatening fair competition and the ability of insurers to participate in mobility ecosystems (Fabian et all 2019, Alaa et al 2025, Lin, X 2025).

- **Knowledge transfer and skills:** due to SDVs fast, iterative software cycles, traditional development and delivery models often struggle to adapt to the iterative demand of new automotive products, and that the transformation of enterprise capability faces multiple challenges (Liu, Z 2022). Skills, culture and organisational structure must adapt along with the technology itself. Software-centric industries (such as chip design and AI) and their respective cultures often function differently, causing knowledge transfer to be hindered when legacy, hardware-centric processes and roles persist (Liu, Z 2022)

- **Data sharing and consumer consent:** From a fleet operations centre perspective, this will be quite important. As more issues are addressed through OTA SW updates (and not HW recalls), there is greater reliance on customers to agree to share their vehicle data and accept updates, particularly when these are safety-critical. Frameworks for managing consumer consent and data protection that are compliant with existing regulations are needed, including the monitoring of updates to monitor their compliance (Tokas and Owe, 2020).

Evidence from SDV ecosystems

Whilst from an ecosystem and business standpoint, analyses of SDVs applications emphasise that value creation is migrating toward software and services. Analysis of the technical literature also shows that the challenges to realising these outcomes remain firmly in the fields of product development, regulatory compliance, stakeholder alignment, knowledge exchange and skills across the ecosystem, and the merging of legacy and emerging technologies.

In response, various approaches to 'opening' the ecosystem have been proposed in the literature, evaluating existing platforms such as Autoware, Safe-

Linux, and Risk-V. Surveys and industry analyses stress the need for standardised software architectures with open APIs and strong safety certification to manage complexity and enable crossdomain reuse (De Vincensi et al., 2024; Liu et al., 2022; Schleicher, 2021). Apex.OS (a safety-certified ROS 2 fork) illustrates a hybrid model: open APIs and ROS heritage, but a proprietary, ISO 26262 ASILDcertified implementation (Becker et al., 2021). This enables ecosystem learning while keeping safety-critical code tightly controlled.

Open, service-oriented middleware (e.g., SOAFEE, Eclipse SDV projects such as Kuksa, Chariott, MoEc.OS) is positioned as a foundation for multivendor integration and mixedcriticality, but is still early in adoption (Teixeira et al., 2024). On the other hand, OEMs like Mercedes (MB. OS), BMW, Stellantis, and GM's Ultifi pursue largely closed, OEMbranded platforms with selected open interfaces and developer APIs to balance IP control with service innovation (Teixeira et al., 2024; Liu et al., 2022).

For safety-critical domains, standards and certification (ISO 26262, ISO/SAE 21434) and deterministic execution are central success factors; open interfaces are encouraged, but core implementations tend to remain closed to manage quality, liability, and governance (De Vincensi et al., 2024; Becker et al., 2021).

A major bottleneck is the lack of open datasets, simulators, and benchmarks, which slows ecosystem learning and independent validation (Khamis & Goswami, 2025). Waymo and Ford have selectively opened curated datasets to stimulate algorithm innovation while preserving competitive IP (Kuru, 2022). Open AD toolchains (Autoware with SOAFEE/Open AD Kit), and open CI/CD and testbeds (e.g., an open-source SDV CI/CD pipeline with OTA middleware) show that open tooling can improve quality control, variant management, and continuous validation across heterogeneous hardware (Pan et al., 2024; Weiss et al., 2025).

Chipletcentric and cloudnative development flows argue for open ecosystems (e.g., open chiplet standards, cloud toolchains) to avoid lockin and increase supplychain resilience (Narashiman et al., 2024).

From a service layers perspective (connectivity, infotainment, ADAS features, MaaS) more open, service-oriented APIs are favoured (Liu et al., 2022; Ohlsen, 2022; Han et al., 2020). OEMs and cloud providers are moving to vehicle–edge–cloud frameworks with open, datacentric platforms to enable third-party and crossindustry collaboration while maintaining secure "control APIs" for vehicle functions (Han et al., 2020). Successful B2C service ecosystems (e.g., applike SDV visions) hinge on robust privacy, OTA governance, and trust frameworks; failures are most likely where marketing overpromises, and technical engineering is limited, legal/ethical frameworks are weak, or security controls are immature (Kuru, 2022; De Vincensi et al., 2024; Sghaier et al., 2025).

Such variation across the value chain, depending on the stakeholders' perspective, appears to have led to fragmentation. Whilst pockets of success are realised, a more holistic form of analysis is required such that UK investments and interventions can be designed that either complement existing initiatives or address gaps. Leading to the question for the UK to exploit the opportunities of the software defined vehicle, what complete system of stakeholders, capabilities and interactions will be required?

Section 2a: What does it take to grow global economic advantage in a new technology sector or sub-sector?

We will now progress to explore evidence around the early foundations that seed growth: scientific knowledge, technological capabilities, and R&D intensity, as well as the broader ecosystem factors, including investment flows, public policy, skills, infrastructure, and institutional arrangements. Central to this inquiry is the recognition that national advantage is rarely created by a single breakthrough. Instead, it grows from the cumulative alignment of technology development, market formation, workforce readiness, and strategic policy choice. We will look at how key capabilities can be organised to maximise potential and consider the impact of well-designed open platforms (which, conversely includes being 'closed' at the right points also) in enabling this momentum shift. Resulting in a refined lens through which to address the SDV question specifically.

The journey of technology to realising economic and societal impact

National advantage in an emerging technology sector rarely stands alone. Wide scale technology shifts (such as to AI, often referred to as general purpose technologies [GPT]) must work in tandem with existing, competitive manufacturing and services bases.

Early national specialisation acts as a seed and depends heavily on preexisting technological capabilities and on how closely new knowledge aligns with existing strengths. Scientific capabilities and publication output are even more powerful than existing complex technologies at the entry stage, with scientific knowledge that is cognitively close to current technological strengths creating the largest gains in AI specialisation and comparative advantage (Chun et al., 2024). This supports a strategy where mature economies map their industrial base and technology capabilities, then identify GPT's (such as AI-computation, electrification, silicone/ chip design and manufacture, cloud computing, 3D printing etc) subdomains where their science and technology portfolios are already complementary, rather than pursuing undifferentiated "catchall" ambitions (Chun et al., 2024). These GPT's then act as engines of GDP growth and productivity by permeating many sectors (healthcare, manufacturing, logistics), enabling innovation, and reshaping production–consumption structures (Kaggwa et al., 2023).

Matching the right blend of public-private investment at the appropriate stage of the development cycle is an important consideration. Evidence from strategic emerging enterprises show that R&D investment is already a strong predictor of later highquality performance; early underinvestment is difficult to reverse (Chun et al., 2024). At the firm level, sustained R&D remains the central quantitative driver of highquality development in the growth stage, supporting continuous product reinvention and longrun innovation capabilities (Chun et al., 2024). For national strategies, this implies that early and persistent public and private R&D funding in targeted domains is essential, especially before commercial returns are clear.

In cleantech and renewable energy, earlystage ventures face combined technology and market risks. Venture capital often favours incremental innovations with clearer exits, creating a financing gap for more radical storage and zeroemission technologies during the seed phase (Nanda and Rhodes-Kropf, 2017). Scaling these sectors requires blended finance: corporate venture capital, specialised VCs, and public support mechanisms to share policy and technology risks (Gaddy *et al.*, 2017). The implication for advanced economies is that "marketonly" funding models tend to underprovide the most transformative technologies; public instruments must deliberately target highrisk, highleverage core technologies. An example of such public intervention is through critical enabling infrastructure, such as the Isambard supercomputer at Bristol University. As sectors mature, investment needs shift from basic R&D toward standardsetting, infrastructure, and platforms, and toward firmlevel capabilities for continuous innovation (Malerba, 2002). Progress can be slow as it is required in <u>*both*</u> the GPT industries themselves (i.e. AI) and the application industries (i.e. Automotive). We should also consider practical enablers, which include transportation links between key industry hubs and GPT hubs (i.e. for automotive and AI linking the West Midlands to Cambridge), and talent/ skills acquisition.

Figure 2 maps these elements, raising the question that a system of this scale cannot feasibly be covered by a single stakeholder (even a government). Therefore, the mechanisms by which stakeholders throughout this system come together warrant significant investigation. Because one of the major risks in realising such a model is at the links between stakeholders.

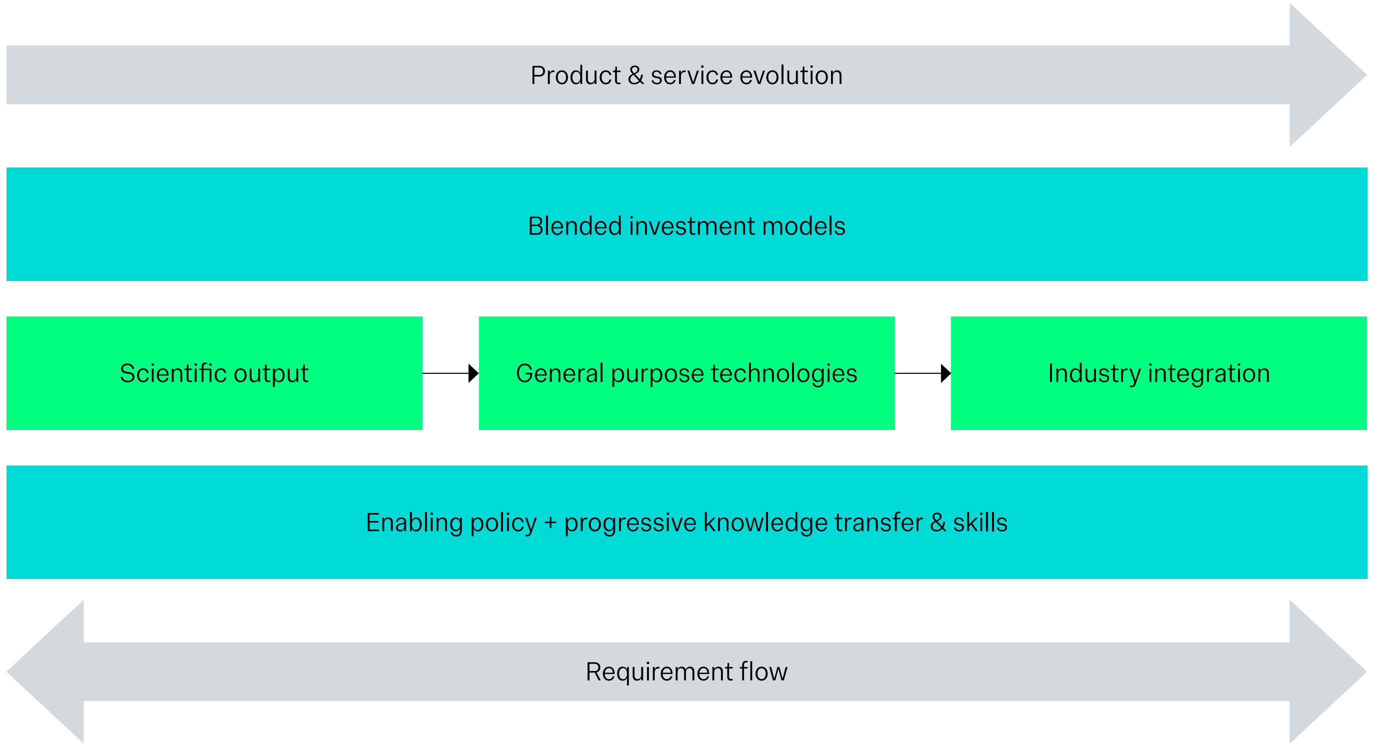


Figure 2: Attributes of a system (platform) required to gain competitive advantage in new technology domains

In response to this challenge, highperforming regions combine strong systems integration in production and organisation with dense university–industry linkages and clusterlevel governance, supporting ongoing technological leadership rather than one-off successes (Asheim and Coenen, 2005) as the innovation processes of firms are strongly shaped by their specific knowledge base. In this paper, we shall distinguish between two types of knowledge base: analytical and synthetic. These types indicate different mixes of tacit and codified knowledge, codification possibilities and limits, qualifications and skills, required organisations and institutions involved, as well as specific competitive challenges from a globalising economy, which have different implications for different sectors of industry, and, thus, for the kind of innovation support needed. The traditional constellation of industrial clusters surrounded by innovation supporting organisations, constituting a regional innovation system, is nearly always to be found in contexts of industries with a synthetic knowledge base (e.g. engineering-based industries. National policy also must balance openness to foreign capital and collaboration in critical technologies with concerns around national security and adversarial capital, particularly in AI, quantum, biotech, and advanced manufacturing. Regional advantage tends to emerge where enabling technologies, ICTs, robotics, AI, are deliberately integrated into existing industrial bases like automotive, aerospace, and machinery, rather than developed in isolation (Cooke, 2001).

In AI, countries with strong scientific knowledge bases and related technological capabilities specialise more successfully in new subdomains, reinforcing longrun competitive advantage (Chun et al., 2024). This suggests that industrial policy should sequence: first, build or leverage a strong science base; second, connect it to adjacent application sectors through joint labs, collaborative consortia, and missionoriented programmes.

More traditional guidance on national competitive advantage in new technologies still holds. Countries must evaluate strengths and weaknesses, monitor trends, and target niches where they can meet world quality standards, ensure efficient infrastructure, and build a skilled workforce (Klus, 2014). Strategic selection of a small number of highleverage core technologies, framed as "national weapons" of competitiveness, becomes central, because they propagate along industrial and technology chains (Eckhardt et al., 2018).

Comparative analysis of open platforms, ecosystems, and national growth

To facilitate the interfaces identified, open platforms and digital ecosystems have become key levers for scaling emerging technologies. Here, we review the evidence on a number of select industries to draw lessons on relevance to our central research question.

Upstream (pre-product sales) ecosystems vs downstream (post-sales) ecosystems
In handheld computing/ smartphones, granting greater upstream access to independent hardware developers (opening technical interfaces, lowering entry barriers) accelerated the rate of new device development by up to fivefold, depending on how access was implemented (Boudreau, 2010). Ceding deeper control over the upstream operating system (governance, roadmap, core design) had an additional but far smaller effect on innovation (Boudreau, 2010). With complementary soft elements, including governance transparency, stability of policies, and credible commitment not to expropriate complementors.

In app store ecosystems (downstream), productspecific information generated within the ecosystem helps entrepreneurs decide when to commercialise previously free applications; platform designers can manage such information flows to support complementor viability (Eckhardt et al., 2018). Informationrich, transparent platforms therefore better support entrepreneurial upgrading.

However alternative evidence within the wider system-of-systems analysis of the smartphone industry finds that limited economic and commercial value capture comes from 'app store' level revenue, with product design and manufacture, connectivity (including substantial upfront CAPEX investments), raw materials and supply chains (Jason L Denick 2011) and ecosystem orchestrators such as Apple and Google governing interactions among users and developers (Schreieck et al 2022) all representing a much larger proportion of value capture.

Extending this reasoning, we can argue that downstream low frication, high competition environments within which comparable app developers operate mean geographic capability clusters that build economic advantage are much less likely to form and/ or will be much more brittle to external competition and quickly shifting to alternative regions.

Open vs closed: no onesizefitsall model
Further complicating the picture across industries, there is not a universally superior "open" or "closed" platform model. Evidence from internet platform enterprises shows that performance depends on how openness interacts with complexity (Wang et al., 2020). When innovation requires high knowledge complexity, high openness can still yield high performance, but only when the platform can orchestrate complex collaboration and manage quality (Wang et al., 2020).

This aligns with the mobile payments case: opening can expand market potential and help reach critical mass, but each level (provider, technology, or user) carries tradeoffs. Openness can increase coverage and adoption but complicates coordination and can introduce risk and fragmentation (Ondrus et al., 2015). Building on this evidence from the mobile payments industry Ondrus et al (2015) propose decision rules to calibrate openness by context, rather than prescribing a fixed model.

Telecommunications has been a leading adopter of open innovation platforms, especially via open innovation systems (OIS) and third-party developer ecosystems. Bersosa et al. (2013) present findings from a case in the telecom industry where a large operator built an open business model around external developers, offering APIs, technical documentation, and business support so that third parties could build complementary services on the operator's infrastructure.

This model's growth mechanism lies in mobilising an external developer community to supply innovative applications and services, supported by clear value propositions and revenue models for third parties (Boudreau, 2010; Eckhardt et al., 2018; Cenamor & Frishammar, 2020; Bersosa et al., 2013). Skills and workforce capability are expanded beyond the operator's internal teams, drawing on global developer talent. Supply chain integration becomes ecosystem integration: the operator acts as platform sponsor, setting technical standards and ensuring interoperability, while enabling diverse partners, banks, application developers, and government agencies to co-create services such as mobile payments or digital government solutions (Ondrus et al., 2015; Muchungu & Mutua, 2024; Bersosa et al., 2013).

These examples draw our attention to the role of how a given ecosystem is intentionally guided to enable dynamic adaptation to market demands, especially in complex manufacturing context.

Ecosystems in safety-critical sectors
In German medical technology clusters, a multi-sided open innovation platform was introduced where hospitals, SMEs, research institutes, and technology providers co-created solutions to defined clinical and technical challenges (Daiberl et al., 2019). The platform's design explicitly tackled workforce capability by mobilising highly specialised SMEs and academic partners that had never used dedicated open innovation systems before, requiring education and coaching on formulating suitable challenges and managing collaborations (Daiberl et al., 2019).

Supply chain integration emerged through configuration of "seekers" (firms with problems) and "solvers" (external experts) around common problem definitions, mediated by a platform operator that handled workflow, communication norms, and evaluation processes (Daiberl et al., 2019). Governance and trust were critical: standardised information and generic guidelines were insufficient, and progress depended on more tailored engagement and clear rules about participation, evaluation, and follow-up (Daiberl et al., 2019).

The Rolls-Royce “power-by-the-hour” model is best seen as an advanced service platform that reconfigures the industry’s value logic around availability rather than asset sales. Jovanovic et al (2016) identify product and context attributes under which such a model thrives: the product must be a critical ancillary input to (B2B) customers’ operations, operate in controllable environments with measurable performance metrics, involve relatively low upfront cost but high total cost of ownership, and entail very high risk and cost if it fails (Jovanovic et al., 2016).

This model implicitly depends on a tightly integrated service and data platform spanning the engine lifecycle: real-time monitoring, predictive maintenance, and coordinated supply networks of parts, MRO (maintenance, repair and overhaul) providers, and airlines. Platform governance ensures that specialised maintenance skills, data standards, and safety procedures are aligned, enabling safe sharing of performance data while strictly managing operational and regulatory risk (Das & Dey, 2021; Jovanovic et al., 2016). The “open” element is not free access but orchestrated participation of multiple partners around shared performance contracts and standardised technical interfaces, enabling continuous improvement and incremental innovation in both hardware and services.

Cross-Cutting Mechanisms and Common Factors
We can see the need to orchestrate skills, supply chains, IP, and safety while accelerating innovation and growth. We can see that across sectors, platform sponsors act as orchestrators, structuring access, standards, and governance to balance openness with control and risk management (Yun & Liu, 2019; Boudreau, 2010; Ondrus et al., 2015; Wang et al., 2020; Das & Dey, 2021).

Where products and services are increasingly safety-critical and/ or have deep complexity of integration between stakeholders a recurring pattern for platform sponsors to have to carefully calibrate openness, providing broad access and standardised interfaces while retaining enough control to manage quality, safety, and strategic direction is seen (Boudreau, 2010; Ondrus et al., 2015; Wang et al., 2020).

Taken together, these cases suggest that open platforms enable industry growth and innovation not simply by being “open,” but by deliberately configuring access, standards, governance, and incentives around the specific technological, regulatory, and risk characteristics of each industry.

Section 2b: Mapping the SDV system

The four step systems thinking approach

As we have found the transition towards software-defined vehicles (SDVs) is reshaping the automotive industry and the wider transport ecosystem. Value creation is no longer limited to vehicle sales or the performance of physical components; it increasingly depends on the ability to integrate software, data infrastructure, supply chain capabilities, workforce skills, regulatory processes, and through-life services. This shift creates a complex socio-technical and commercial system in which technical performance, organisational responsibilities, safety assurance, and financial viability are closely interconnected.

The System-Theoretic Accident Model and Processes (STAMP) perspective has helped shift the focus from linear accident causation to understanding accidents as emergent properties of complex socio-technical systems (Leveson and Thomas, 2018). STAMP-based methods, such as System-Theoretic Process Analysis (STPA), is defined as a four-step, top-down hazard analysis method that models systems as hierarchical control structures and examines how inadequate control, flawed decision-making, and dysfunctional interactions can lead to hazardous system states. However, while STPA can reveal what might go wrong, it does not guarantee that identified hazards and assumptions will remain valid once systems are deployed.

Within this context, disruptions may not arise only from technical component failures. They may also emerge when expectations and beliefs about system behaviour, stakeholder responsibilities, data availability, infrastructure readiness, operational performance, or market conditions become invalid. These assumptions often underpin decisions made during early design, development, deployment, and commercialisation.

This creates a need for a structured approach that can identify not only hazards and risks, but also dependencies, gaps, weak signals, and growth opportunities across the SDV ecosystem. In this project, a systems-thinking approach inspired by STAMP\STPA is used to support the identification of risks, interventions, and opportunities that can strengthen the UK automotive ecosystem and support the safe and commercially viable deployment of SDVs (El Badaoui et al., 2026).

As shown in Figure 3, the approach is structured around four steps:

1. **Identify the stakeholders and system boundary:** This step defines the scope of the analysis by identifying the key stakeholders, system boundary, and relevant parts of the SDV ecosystem.

2. **Model the interactions:** This step captures the control actions, feedback loops, information flows, and dependencies between stakeholders.

3. **List assumptions:** This step identifies the assumptions embedded within stakeholder interactions, including expectations about system behaviour, responsibilities, performance, and operating conditions.

4. **Monitor assumptions:** This step translates assumptions into measurable leading indicators, monitors their validity over time, and identifies interventions when assumptions are no longer valid.

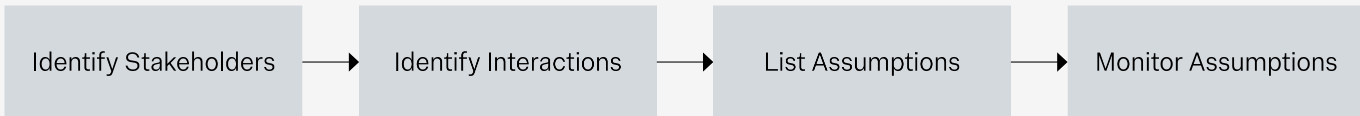


Figure 3: Overview of the Systems Thinking Approach

Step 1: List stakeholders:

The first step establishes the purpose and boundary of the analysis and identifies the stakeholders that influence, operate within, or depend on the system. In this project, the boundary is centred on the SDV ecosystem as an automotive-led but technology-enabled system. The focus is not limited to the traditional vehicle value chain; it also includes the enabling digital, software, data, telecommunications, cybersecurity, semiconductor, and infrastructure capabilities that support SDV development, deployment, operations and commercialisation. Taken together, they shape the system lifecycle from regulation and development through to operation, maintenance, and retirement.

Defining this boundary is essential because it clarifies which actors are relevant to the study, how responsibilities are distributed, and where dependencies arise across the SDV ecosystem. It also supports the later identification of gaps and opportunities by distinguishing between actors within the core automotive value chain and enabling technology actors whose capabilities are necessary for SDV commercialisations and through-life value creation.

Step 2: Modelling structure and control

Step 2: Model the Control Structure: The second step develops a nested control structure that represents the interactions between stakeholders. These interactions are expressed through control actions and feedback, see *Figure* 4. SDVs are shaped by interactions across multiple levels, including regulation, organisations, supply chain, and technical subsystems. Control actions represent how one stakeholder influences another, while feedback represents the information returned from the controlled part of the system. Model stakeholders' interactions allow the analyses to capture responsibilities, decision rights, incentives, and dependencies that may be less visible in a purely technical model. This is important because many SDV-related opportunities emerge where accountability is shared, feedback is delayed, or responsibilities are fragmented across organisational and technical boundaries.

The resulting control structure, therefore, provides more than a visual representation of the system: It reveals how decisions and constraints at one level can affect safety, performance, commercial viability, and opportunities at another. It also helps expose weak coordination, missing feedback, and critical dependencies, forming the basis for identifying where further investigations are required.

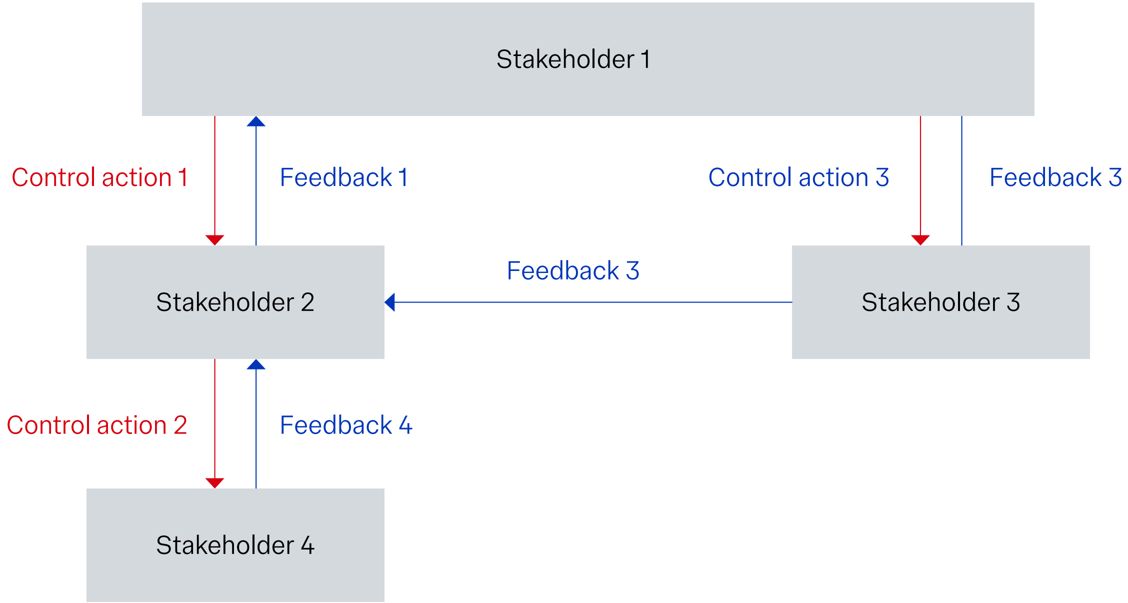


Figure 4: Generic Control structure, red arrow refers to Control action, blue arrow presents feedback

Step 3: Exposing Assumptions

Step 3: List assumptions: Once the control structure has been modelled, the next step is to identify the assumptions embedded in each closed loop. Each control relationship depends on beliefs about how the system is expected to behave, how responsibilities are understood, how decisions are implemented, how information is shared, and how feedback is generated, interpreted, and acted upon. These assumptions reflect the mental models and operating expectations held by stakeholders when issuing, implementing, or responding to control actions within their area of responsibility.

Making these assumptions explicit is important because many system weaknesses do not arise from the absence of control alone, but from misplaced confidence that a control action is valid, that a responsibility is understood, or that feedback is sufficient to support safe decision-making. By surfacing these underlying beliefs, the analysis can reveal where the system relies on fragile coordination, weak evidence, incomplete information, or overly optimistic expectations. This provides a stronger basis for identifying not only technical vulnerabilities, but also organisational and commercial constraints that may affect the viability of SDV deployment.

Step 4: Monitoring

Step 4: Monitor Assumptions: As the system evolves, assumptions may weaken, drift, or become invalid. The fourth step, therefore, translates each assumption into a form that can be monitored in practice. This is achieved by defining measurable indicators, called leading indicators (LIs), alongside thresholds that signal degradation and interventions that can restore the system to an acceptable state.

This monitoring step is central to the value of the approach. It enables the analysis to move beyond static description and towards practical evaluation of whether the current system is adequately equipped to sustain its intended behaviour. Where assumptions are weakly supported or where indicators are exceeded, the analysis identifies gaps in capability, evidence, coordination, or governance. These gaps can then be interpreted as the basis for opportunities: targeted capabilities, services, or organisational interventions that would strengthen the control loops and improve system performance.

Findings and analysis

The Systems-Thinking Approach first established the stakeholder boundary and listed the stakeholders involved in the SDV ecosystem, and then represented the control structure, to ensure capturing all essential stakeholders' control actions and feedback interactions. Two different phases were modelled the first one for pre-operational deployment of the SDV, the second related to post-deployment of the SDV.

This made visible the actors, interfaces, and dependencies required for a full understanding of capabilities and values generated from the SDV deployment through the whole lifecycle.

The control structure modelled provided the analytical basis for identifying which stakeholders should be treated as key partners, which actors are actual customers or beneficiaries, and which interfaces constitute meaningful channels and customer relationships.

At a high level, the SDV ecosystem is represented through two complementary control structures:

- *Reaching commercial viability (R&D) control structure* (Figure 5): Captures the pre-deployment phase, where SDV capabilities are researched, developed, integrated, and shaped into a viable proposition.
- *Post-deployment (operational) control structure* (Figure 6): Captures the through-life operation of the SDV once deployed in the real world.

The two control structures are connected across the SDV lifecycle, together, these figures distinguish between the interactions required to develop an investable SDV proposition and those required to operate and sustain it once deployed. Also, the assumptions made during the R&D about safety, technical readiness, user behaviour, infrastructure availability, regulation, and commercial value must be monitored during operation.

Reaching commercial viability (R&D) control structure:
The conception-phase control structure, Figure 5, represents the system in the design mode and before physical deployment, when the primary activities are regulation and policy setting, funding decisions, architectural design, standards alignment, and feasibility validation, also senses the customer needs and shapes the trust. At this stage, the dominant control relationships are strategic and preparatory rather than operational. Control actions typically take the form of development and introduction of enforcement of regulations and law, technical standards, funding and investment allocations, portfolio prioritisation of features and release and test plans, business case development, brand and product alignment, manufacturing readiness, and preparation for scaled deployment. Feedback mainly consists of feasibility studies, compliance evidence, cost and schedule estimates, skills pipeline and capabilities availability, simulation results, and early assurance evidence and also prepares infrastructure, starting from charging spots to telecom and network communications.

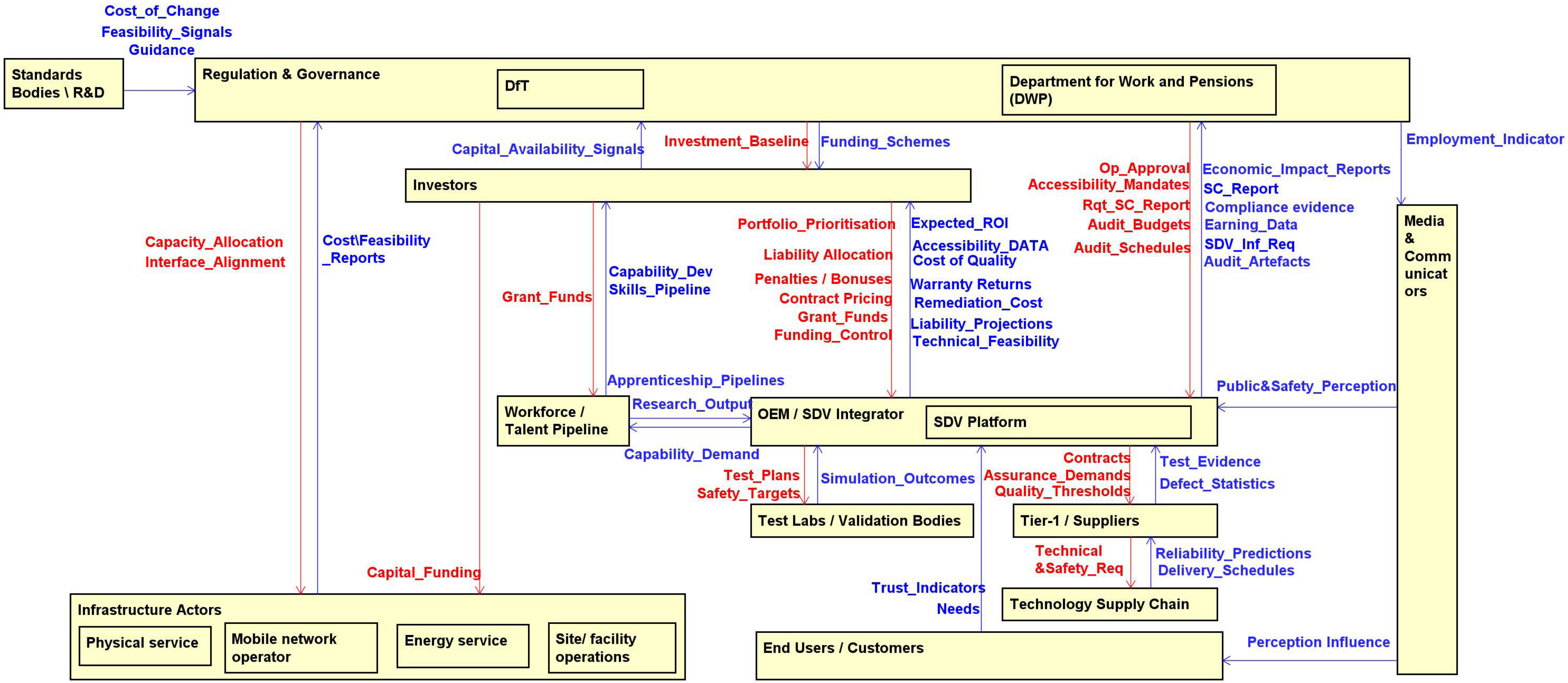


Figure 5: Control structure representing the SDV ecosystem during the concept phase, where red arrows denote control actions and blue arrows denote feedback

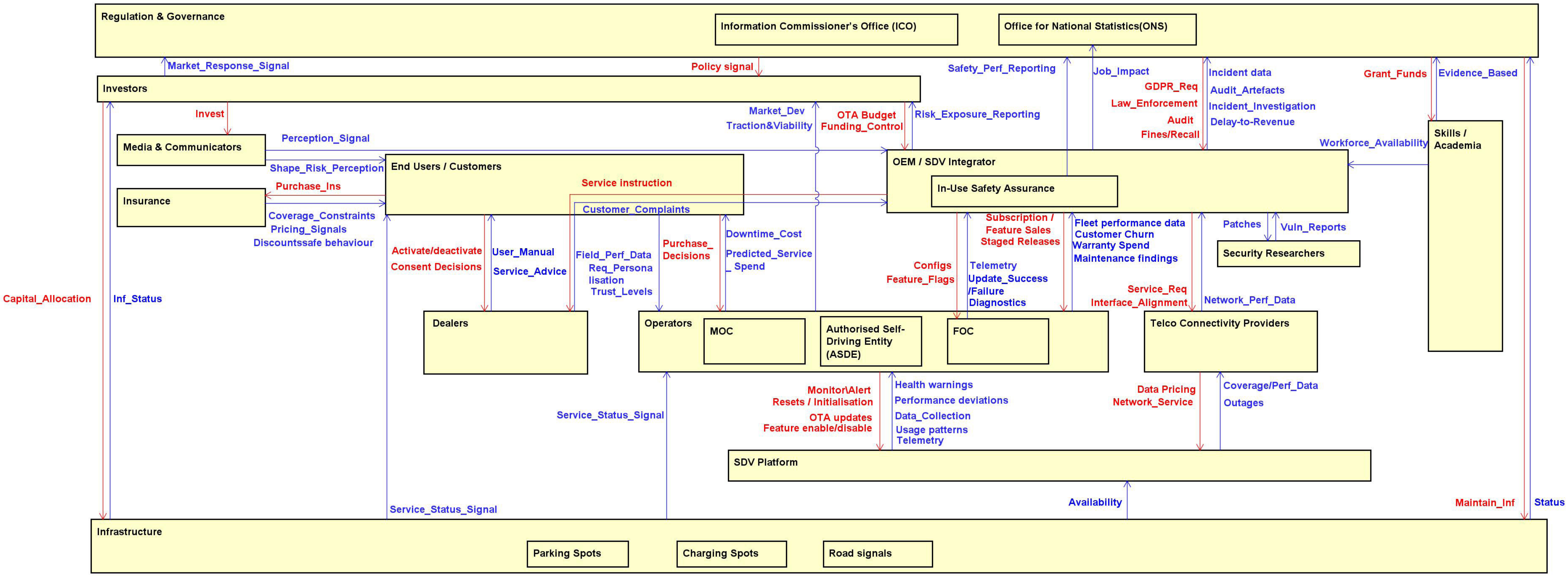


Figure 6: Control structure representing the SDV ecosystem during the operational phase, where red arrows denote control actions and blue arrows denote feedback

Post-Deployment (Operational) Control Structure: The post-deployment control structure Figure 6, represents the system after release into real-world operation, where the focus shifts from planning and regulations to continuous control, monitoring, maintenance, and adaptation. At this stage, the hierarchy of the control structure also changes. In the pre-deployment phase, power is mainly focused on actors that define the SDV concept, allocate investment, set requirements, and approve designs. After deployment, control becomes more distributed across those responsible for operating, regulating, updating, and insuring. In this phase, control actions include OTA updates, feature enable/disable commands, recall instructions, service procedures, insurance incentives, and regulatory enforcement actions. Feedback becomes predominantly consisting of telemetry, incident reports, performance deviations, customer satisfaction and complaints, repair outcomes, network outages, utilisation statistics, and public perception signals.

The authority here, therefore, becomes more dynamic: OEMs continue to impact vehicle behaviour through updates and feedback received, influence user and fleet behaviour through pricing and incentives, and users or fleet operators affect system performance through acceptance, usage, reporting, and maintenance decisions.

The next stage of the analysis elicited assumptions from the closed loops by examining what stakeholders believe when providing and interpreting control actions within their areas of responsibility. This step exposed where the operation of the use case depends on beliefs that may be weakly evidenced, fragmented across suppliers, or vulnerable to change as the SDV platform evolves. To demonstrate how the model can move from an ecosystem-level view to a specific SDV application, Figure 9 and Figure 12 narrow the analysis to the actors directly involved in the design, integration, and delivery of the core SDV platform capability.

While the higher-level control structure captures the broader stakeholder environment and strategic interactions across the ecosystem, the case study walkthroughs provide a narrower application-level view. A specific section, as presented in Figure 7 and Figure 8, of these control structures was then expanded to examine the OEM, SDV platform, and technology supply chain, insurers, service providers, and end users in greater detail. *The Battery Health, Charging, and Lifecycle Value Management, Secure Software Platform Integration and Update Assurance*, and *SDV insurance pricing* cases each focus on the actors, control actions, feedback loops, and dependencies most relevant to that specific application. This allows the analysis to examine how the systems thinking approach can be applied across different forms of SDV value creation, from technical monitoring to operational update control to data-enabled insurance services.

This provides a stronger basis for identifying gaps, opportunities, and commercially relevant capabilities that might be hidden within the higher-level ecosystem view alone. It also demonstrates that the model is not fixed to one SDV application, but can be reused as new technologies, services, suppliers, and business models emerge.

Figure 7: Derivation of the zoomed-in control structure from the higher-level SDV ecosystem control structure. The upper diagram presents the wider stakeholder and control relationships across the SDV ecosystem, while the lower diagram expands the selected OEM,SDV platform, and technology supply-chain area to capture more detailed control actions, feedback signals, assumptions, and dependencies for the case study analysis

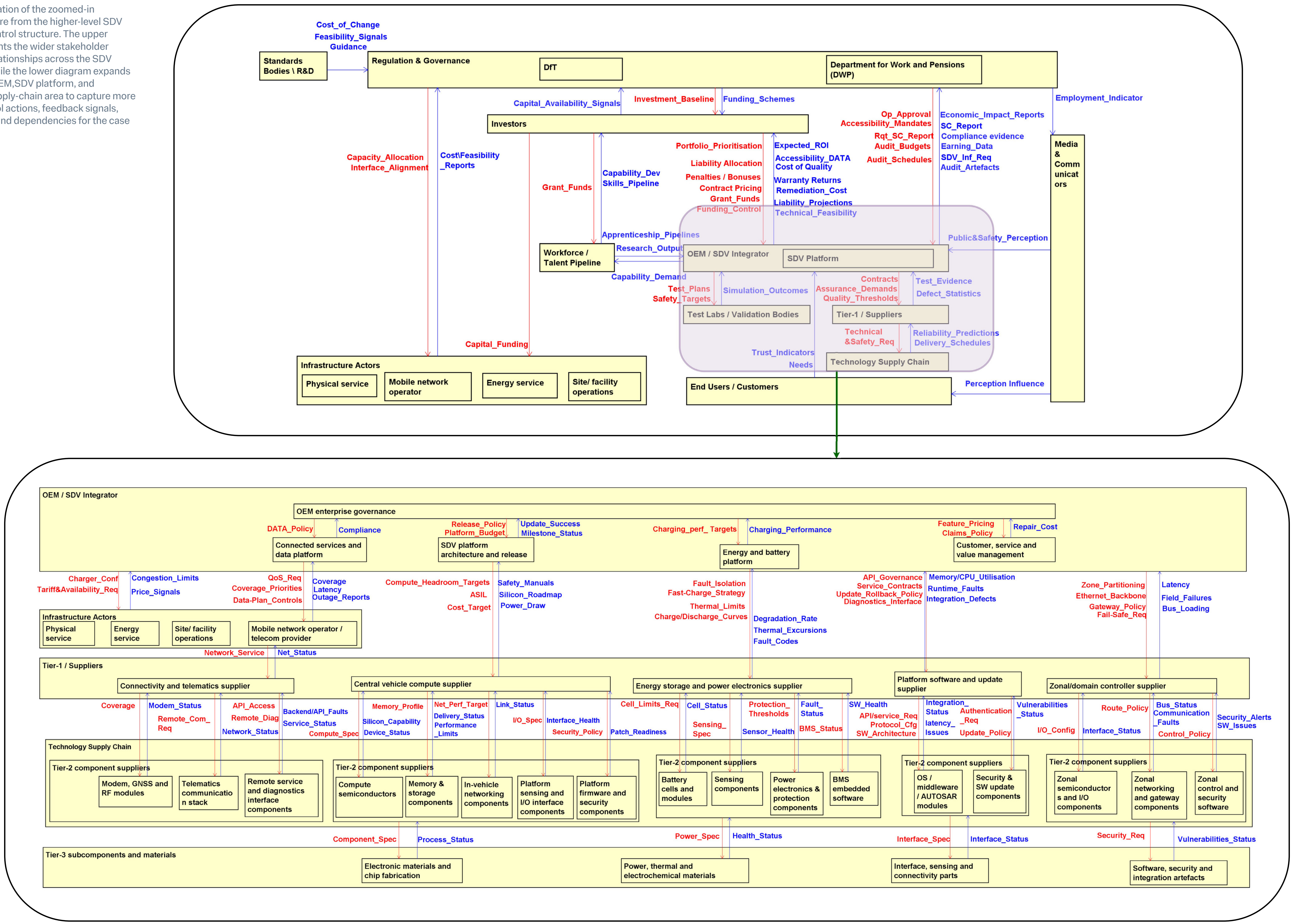
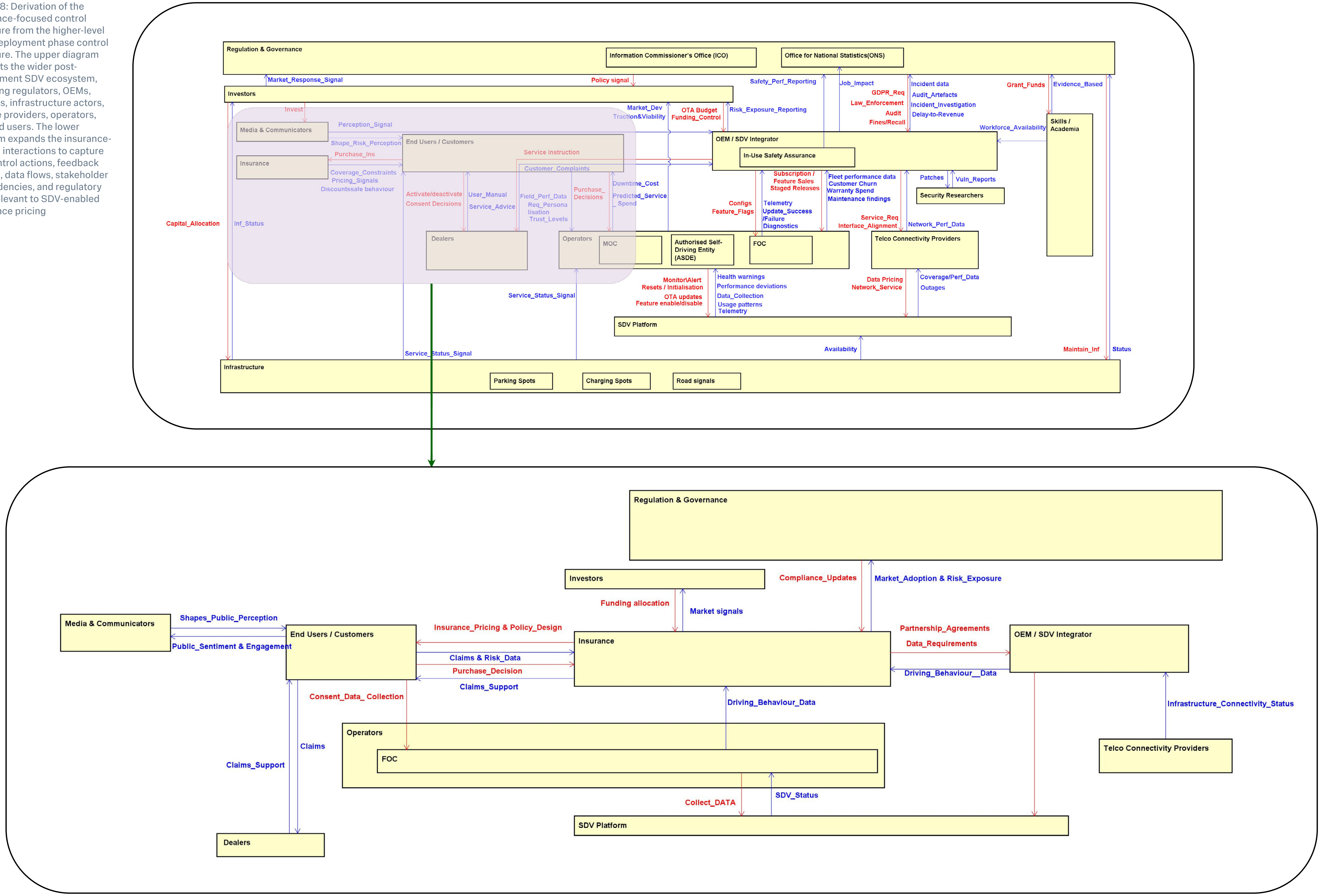


Figure 8: Derivation of the insurance-focused control structure from the higher-level post-deployment phase control structure. The upper diagram presents the wider post-deployment SDV ecosystem, including regulators, OEMs, insurers, infrastructure actors, service providers, operators, and end users. The lower diagram expands the insurance-related interactions to capture the control actions, feedback signals, data flows, stakeholder dependencies, and regulatory links relevant to SDV-enabled insurance pricing



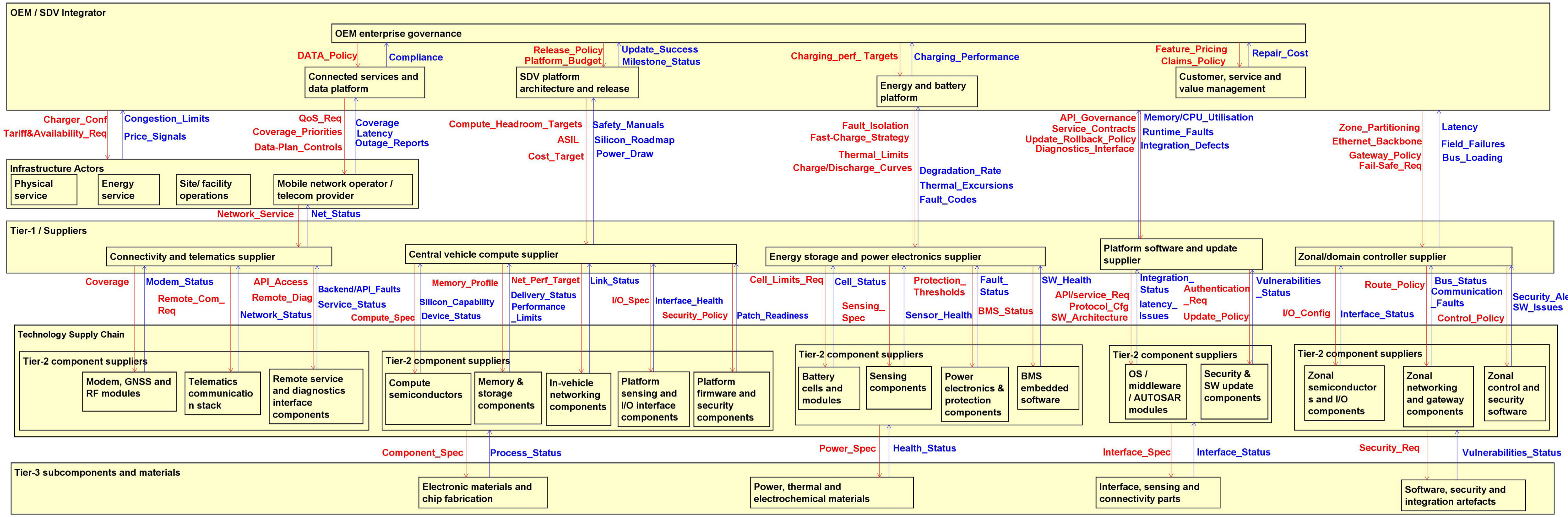


Figure 9 : Zoomed-in control structure of the SDV platform, illustrating the lower-level closed-loop interactions between the OEM, platform, and Tier 1 to Tier 3 actors within the wider ecosystem model, where red arrows denote control actions and blue arrows denote feedback

Case Study 1: Battery Health, Charging, and Lifecycle Value Management

The main result of this case study is that the value of the SDV battery domain is not limited to hardware performance. The control structure in Figure 10, showed that value depends on coordination across the energy and battery platform, battery system suppliers, cell and module suppliers, sensing and protection suppliers, and customer-facing operating conditions. This means the battery system should be understood as a managed socio-technical service rather than as a static product.

The listing assumptions in step 3, then made visible where these two stakeholders, *"Energy and battery platform"* and the *"Energy storage and power electronics supplier"* in Figure 10, might depend on fragile beliefs: for example, assumptions on these control actions *"Fault-Isolation"* matches the actual battery condition, that "Fast-Charging" strategies are suitable for real battery states, that thermal limits reflect actual operating capability, and that Cell-level limits and sensing specifications remain sufficient across production variation and ageing.

The key results from this step are not only to list these assumptions with emphasis on technical risk, but also to highlight the process model beliefs of these stakeholders and highlight the dependency on cross-tier coordination, and this is exactly the hidden vulnerability that this step is trying to highlight.

From this, the main gaps become clearer:

- limited confidence in real-world battery behaviour across use contexts,
- weak visibility of degradation and variation across tiers,
- insufficient assurance that charging, sensing, and protection decisions remain valid through life,
- fragmented ownership of battery lifecycle value.

Those gaps then lead directly to opportunities:

- battery-health analytics,
- adaptive charging services,
- lifecycle value assurance,
- warranty-risk reduction,
- second-life and residual-value support,
- stronger battery data integration across OEM, Tier 1, and Tier 2.

As a result of Step 4, the systems-thinking outputs did not only identify what value could be offered, but also what assurance activities, capabilities, data resources, and governance arrangements would be required to sustain that value over time.

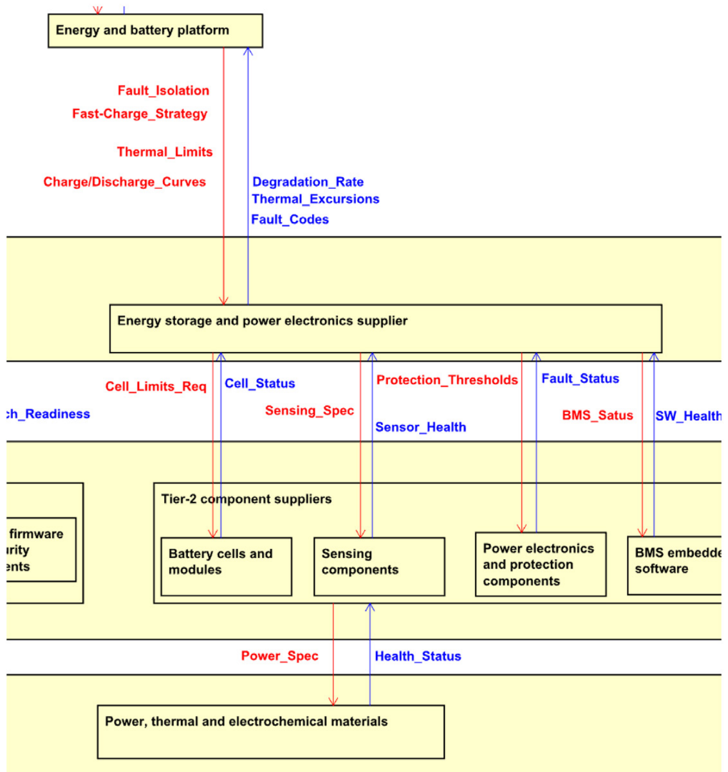


Figure 10: Extracted control loop representing battery health assessment and charging control, focusing on assumptions associated with control actions (red arrows) issued by the "Energy and Battery Platform" and the "Energy Storage and Power Electronics Supplier"

Results from Case Study 2: Secure Software Platform Integration and Update Assurance

The results of this case study show that, within the SDV ecosystem, see Figure 11, update governance and platform integration constitute elements of system performance and lifecycle value. The control structure highlights that value depends on coordinated interactions between the OEM, the SDV platform, middleware and software suppliers, and security and integrations actors. As a result, software capability should be interpreted not as an isolated technical layer, but as a managed, cross-stakeholder system in which the closed loop must be consistent across organisational and technical boundaries.

The listing assumptions step makes visible where this system depends on implicit beliefs and expectations regarding software behaviour, protocol configuration, API and service requirements, and expectations on the authentication process and requirements.

Assumptions emphasise expectation on how software architecture remains compatible across system layers, protocol configurations support reliable communication, and authentication mechanisms are consistently enforced, and that update policies can be executed without undermining the system's safe state. The key outcome of this step is the identification of dependencies on cross-tier coordination and governance rather than on a single component alone.

After completing this step, the gap becomes clearer.

- Limited assurance of integration across the software layer,
- Insufficient robustness of update deployment and rollback processes,
- Lifecycle management,
- Potential inconsistencies in authentication and access control.

These gaps indicate that the current process may struggle to maintain reliable, secure, and scalable software operation.

These gaps then led to opportunities, which include:

- Development of secure and scalable OTA updates,
- Improved software integration and validation services,
- Enhanced authentication and access management.

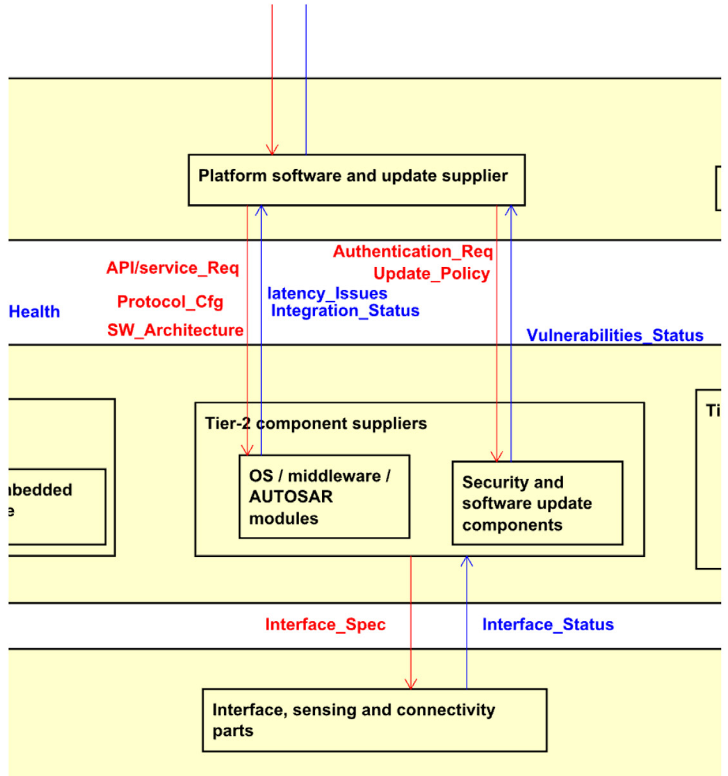


Figure 11: Extracted system loop representing the Software Platform Integration and Update Assurance control structure, showing the control actions (red arrows) issued by the "Platform Software and Update Supplier", which form the basis for listing assumptions and demonstrating the approach in this case study.

Results from Case Study 3: SDV- insurance pricing case study

This case study explores a different perspective by examining how the systems-thinking approach can support the structured identification of opportunities and gaps associated with insurance pricing for software-defined vehicles in the United Kingdom.

The transition to SDVs introduces a complex ecosystem involving OEMs, insurance providers, regulators, infrastructure operators, and end users. Within this ecosystem, insurance pricing shifts from static, historical models to dynamic, data-driven pricing mechanisms based on real-time vehicle usage and driver behaviour.

Figure 9 presents a focused view of the control structure, highlighting control actions and feedback loops specific to insurance pricing. In particular, data-sharing partnerships between OEMs and fleet operation centres play a critical role in enabling insurers to evaluate driver behaviour. This behavioural data not only supports more accurate pricing but also creates incentives for customers to adopt safer driving practices and comply with regulatory recommendations, ultimately reinforcing the value proposition of usage-based insurance models.

Each stakeholder operates based on implicit assumptions regarding data availability, system performance, customer willingness to share data, regulatory acceptance, and the commercial viability of usage-based pricing models. However, many of these assumptions listed may not hold once the system is deployed in a real-world and evolving environment. This creates significant uncertainty for insurers, particularly in their ability to accurately assess risk and price policies, potentially leading to mispricing, increased loss ratios, or delayed market adoption.

The Systems Thinking framework addresses these challenges by making stakeholder-specific assumptions explicit and linking them to measurable leading indicators and decision thresholds. For example, assumptions related to data sharing between OEMs and insurers can be evaluated through the availability, quality, and accessibility of vehicle and behavioural data within existing UK data governance frameworks.

This approach also enables the systematic identification of gaps, which directly impact insurance pricing as follows:

- Unclear data governance requirements.
- Challenges between vehicle systems and insurance platforms, and potential lack of customer trust in data collection.
- Limited risk-modelling capability for SDV-generated behavioural data,
- Insufficient access to high-quality and standardised data,
- Uncertainty around customer acceptance of behaviour-based pricing.
- Absence of clearly defined agreements between OEMs, insurers, and other relevant partners for accessing and using vehicle and behaviour data.
- Uncertainty around whether continuous and reliable data streams can be maintained for dynamic risk evaluation and pricing decisions.
- Possible reluctance from customers to share personal driving or behavioural data due to privacy, transparency, or trust concerns.

By explicitly linking these gaps to targeted interventions, opportunities can be created, such as:

- Data-sharing agreements: establish formal agreements between OEMs, insurers, and relevant ecosystem partners to support reliable and compliant data access.
- Data standardisation: develop common data formats, definitions, and quality requirements to improve the usability of SDV-generated data for insurance pricing.
- Improved risk modelling: use richer behavioural and vehicle data to support more accurate, dynamic, and personalised insurance pricing models.
- Customer transparency mechanisms: provide clear explanations of what data is collected, how it is used, and how it affects pricing to improve customer trust and adoption.
- Scalable behaviour-based pricing: develop insurance models that can adjust dynamically based on customer behaviour, if data reliability, customer consent, and system interoperability are addressed.

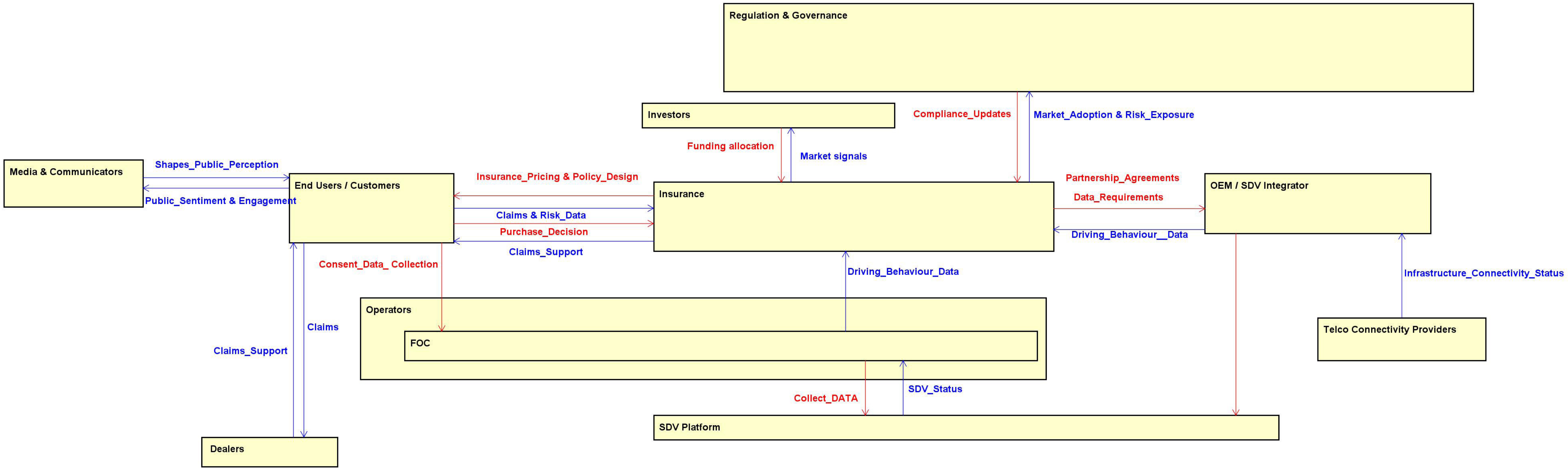


Figure 12: Control structure of the SDV-enabled insurance pricing case study (red arrows: control actions; blue arrows: feedback).

Section 2c: From systems-thinking to stakeholder decision making

The Business Model Canvas (BMC) is adopted in this study as an established framework for organising the main attributes of commercial decision-making in innovation and research contexts. Business models are commonly understood as mechanisms through which organisations create, deliver, and capture value. The BMC provides a concise visual structure for representing these elements through interrelated components, including value propositions, key activities, key resources, channels, customers, cost structures, and revenue streams (Osterwalder and Pigneur, 2013). This makes the BMC a useful synthesis mechanism for translating analytical outputs into a format that can support organisational and ecosystem-level decision-making.

However, the BMC also has recognised limitations. When used independently, it can rely heavily on the judgment of the participants and may not provide a sufficiently structured mechanism for ensuring that all relevant sources of value, system dependencies, stakeholders, and external conditions have been identified (Widmer, 2016). Previous studies have argued that the BMC can oversimplify complex business environments, provide limited support for dynamic system change, and require adaptation when applied to multi-stakeholder, product service, circular economy, or platform-based contexts (Teece, 2010) (Vatankhah *et al.*, 2023). These limitations are particularly relevant to SDV ecosystems, where value creation depends on interactions between OEMs, suppliers, regulators, infrastructure, actors, service providers, data platforms, and end users. In this study, the BMC is not used as a standalone brainstorming exercise, but as a communication and synthesis layer through which the outputs of the Systems Thinking Approach are organised into a holistic representation of how value may be created and captured within the SDV ecosystem.

Accordingly, structured synthesis of the Systems Thinking Approach outputs. The control structure identifies the main stakeholders, interactions, and hierarchy within the SDV ecosystem. The assumptions elicited in Step 3 reveal where closed loops rely on beliefs and expectations that may be weakly evidenced or vulnerable to change, and Step 4 identifies the capabilities, monitoring metrics, and corrective interventions required to sustain loop performance and preserve assumption validity.

As a result, the BMC is derived from the analytical outputs of the Systems-Thinking Approach, rather than from abstract commercial reasoning alone. Thereby, grounding the resulting business model in observed system dependencies, identified gaps, and emerging opportunities rather than in abstract commercial reasoning alone.

The use of the BMC is aligned with its established purpose as a framework for describing how an organisation creates, delivers, and captures value across nine building blocks. As presented in the *Business Model Generation Handbook* (Osterwalder and Pigneur, 2013). These blocks are accompanied by guiding questions, for example, *"Who are our key partners?"* and *"Who are our key suppliers?"* which help structure the analysis of each business model element, see Figure 13. In this study, those questions are answered through evidence generated by the Systems Thinking Approach, thereby linking system analysis directly to business-model development.

The business model canvas as a decision-making tool

The first two steps help identify the stakeholders, hierarchy, and interdependencies that are most relevant to the SDV ecosystem. This provides the basis for identifying **Key Partners**, as well as the customer-facing interfaces that shape **Channels** and **Customer Relationships**. The principal control actions performed by the main stakeholders, together with the monitoring, validation, escalation, and interventions identified in Step 4, inform the **Key Activities** required to operate and sustain the system over time. The capabilities, data, engineering expertise, software, governance arrangements, and infrastructure needed to perform these activities form the basis of the **Key Resources**.

The **Value Proposition** is grounded in the opportunities revealed through the assumption and monitoring analysis. In this study, these opportunities are not treated as abstract possibilities, but as targeted responses to gaps exposed by the Systems-Thinking Approach. **Customer Segments** are derived by filtering the stakeholders identified within the system boundary to determine which actors are the intended beneficiaries, users, adopters, or paying customers of the focal value proposition. The **Cost Structure** is informed by the activities, resources, monitoring effort, compliance requirements, integration work, and corrective interventions needed to keep the focal control loops effective in operation. Finally, **Revenue Streams** are derived from the ways in which the identified opportunities can be translated into captured value, for example, through service provision, subscriptions, licensing, performance-based arrangements, or avoided losses.

Key Partners
- Who are our Key Partners?
- Who are our key suppliers?
- Which Key Resources are we acquiring from partners?
- Which key activities do partners perform?

Key Activities
- What Key Activities do our Value Propositions require?
- Our Distribution Channels?
- Customer Relationships?
- Revenue streams?

Key Resources
- What Key Resources do our Value Propositions require?
- Our Distribution Channels? Customer Relationships?
- Revenue Streams?

Value Propositions
- What value do we deliver to the customer?
- Which one of our customer's problems are we helping to solve?
- What bundles of products and services are we offering to each Customer Segment?
- Which customer needs are we satisfying?

Customer Relationships
- What type of relationship does each of our Customer
- Segments expect us to establish and maintain with them?
- Which ones have we established?
- How are they integrated with the rest of our business model?
- How costly are they?

Channels
- IChannels
- Through which Channels do our Customer Segments
- want to be reached?
- How are we reaching them now?
- How are our Channels integrated?
- Which ones work best?
- Which ones are most cost-efficient?
- How are we integrating them with customer routines?

Customer Segments
- For whom are we creating value?
- Who are our most important customers?

Cost Structure
- What are the most important costs inherent in our business model?
- Which Key Resources are most expensive?
- Which Key Activities are most expensive?

Revenue Streams
- For what value are our customers really willing to pay?
- For what do they currently pay?
- How are they currently paying?
- How would they prefer to pay?
- How much does each Revenue Stream contribute to overall revenues?

Figure 13: Business Model Canvas illustrating the nine categories and the corresponding guiding questions used to interpret the outputs of the analysis

Case Study 1: Battery Health, Charging, and Lifecycle Value Management

The first case study shows that the battery-related value in SDV is not restricted to the physical layer of the battery pack, as shown in Figure 14. Instead, the value arises from the coordination of multiple actors across the energy and storage platform unit control loop, including the Tier 1-Energy storage and power electronics supplier, lower-tier sensing and protection suppliers, charging services interfaces and downstream services functions. For this reason, the business model output for this case places strong emphasis on key partners that can support battery performance and charging control diagnostics and lifecycle decision making, rather than viewing the battery as an isolated component.

The key activities in this case are derived from the control structure and how they are maintained throughout the whole lifecycle.

Activities such as charging optimisation, thermal management calibration, degradation assessment, fault handling, and battery health analytics are complemented by monitoring, supervision, and intervention. In step 4 of the systems thinking approach, the output of this step does not merely add performance metrics as leading indicators, but also reveals the operational work required to keep the value proposition valid. Accordingly, the key resources in the BMC are not limited to Hardware assets. They also include battery state data, analytics capability, diagnostic infrastructure, calibration expertise, and software-embedded monitoring capabilities.

The value proposition emerges from the gaps and opportunities identified through Steps 3 and 4. Where the control loop reveals uncertainty and gaps in fast charging suitability, thermal behaviour and sensing confidence or protection logic, corresponding opportunities become battery health analytics, adaptive charging services, and lifecycle value assurance.

Key Partners
- Tier-1 battery and power-electronics suppliers, Tier-2 cell/module, sensing and protection suppliers, charge-point operators, energy retailers and aggregators, telematics and cloud providers, dealer and service networks, recyclers and second-life partners, regulators.
- Cells and modules, sensing hardware, protection components, BMS embedded software, charging interface components, cloud analytics services, digital traceability tools.
- Validated cell data, supplier traceability records, sensing and protection hardware, charging-network interfaces, battery health analytics inputs, service and residual-value evidence.
- To secure safe battery performance, reduce warranty leakage, enable smart charging, prove compliance and traceability, and create lifecycle value beyond first vehicle sale.

Key Activities
- Battery health estimation, smart-charge optimisation, thermal and fault management, OTA calibration management, warranty analytics, lifecycle reporting, and service triage.
- App and fleet-dashboard integration, dealer diagnostic workflows, energy-partner APIs, and battery health reporting that support customer-facing channels.
- Proactive battery care guidance, service escalation, warranty support, and evidence-based customer communications.
- Subscription management, smart-charging revenue settlement, battery-health certificate generation, warranty-product design, and fleet service contract support.

Key Resources
- Battery telemetry, health models, OTA pipeline, digital thread, supplier traceability, analytics platform, and validated charge/discharge envelopes.
- Mobile app, fleet portal, dealer tools, partner APIs, in-vehicle HMI, and remote diagnostics interfaces.
- Diagnostic portal, remote support tools, service case management, and battery-health history for transparent interactions.
- Billing and settlement logic, battery-health scoring, warranty-cost models, charging-savings analytics, and partner revenue-share controls.

Value Propositions
- Lower degradation and charging cost, higher vehicle uptime, safer battery operation, and clearer battery-health transparency.
- Uncertain battery life, opaque battery condition, avoidable fast-charge stress, downtime from battery events, and high service or warranty cost.
- Battery-health subscription, smart-charging service, fleet battery dashboard, warranty extension, remote diagnostics, and battery-health certificate.
- Trust in battery life, predictable charging, lower total cost of ownership, and vehicle uptime.

Customer Relationships
- Continuous digital guidance, transparent alerts, proactive service support, and evidence-backed warranty interactions.
- Battery status notifications, periodic health scoring, service reports, OTA update notices, and fleet performance dashboards.
- Integrated with the OEM connected platform, energy partners, dealers, and fleet support.
- Moderate to high initially because of integration, validation, and support setup.

Channels
- Partner portal, integration - In-vehicle prompts, OEM mobile app, fleet portal, dealer and service channels, and selected energy-partner apps.
- OEM connected app, dealer service visits, fleet account support, and selected pilot integrations with charging and energy partners.
- Mobile app for retail users, fleet dashboard for commercial operators, and dealer diagnostic tools for issue resolution.
- API-based partner channels, automated self-service diagnostics, and digital subscription management are the most cost-efficient.
- Charging recommendations appear in normal charging routines, fleet maintenance dashboards surface battery actions, and service escalation is triggered by battery condition.

Customer Segments
- Fleet operators, leasing companies, and after-sales service partners.
- Robottaxi and leasing channels that are most exposed to battery life, uptime, and resale value risk.

Cost Structure
- Cell and sensor validation, cloud analytics, OTA management, service support, warranty reserve, partner integration, cybersecurity, and compliance costs.
- Telemetry and data platform, battery models, supplier traceability system, and fleet-facing analytics tools.
- Battery health modelling, charging optimisation validation, supplier quality assurance, field issue triage, and warranty analytics are most expensive.
- Value-driven in the early market, with growing pressure to improve cost efficiency as fleet scale and service automation increase.

Revenue Streams
- Battery life extension, lower charging cost, reduced downtime, and transparent health evidence.
- Vehicle purchase price, energy tariffs, service plans, extended warranty, maintenance contracts, and fleet software subscriptions.
- Upfront vehicle purchase, monthly lease or fleet contract, charging bills, service-plan payments, and ad hoc warranty purchases.
- Monthly subscription, energy-tariff bundle, or per-vehicle fleet contract with service tiers.
- Battery-health subscription, warranty extension, partner revenue share, battery-health certificate, and premium support packages.
- Monthly fee, per-vehicle-per-month pricing, shared-savings charging model, and OEM offers.

Figure 14: Synthesis of the Systems-Thinking Approach into a Business Model Canvas for the Battery Health, Charging, and Lifecycle Value Management case study

Case Study 2: Secure Software Platform Integration and Update Assurance

The second case study demonstrates that software architecture, update governance and platform integration should be treated as core business model elements in SDV ecosystem, see Figure 15. The control structure in this case highlights different types of interactions from the first case study: here, commercial value depends on whether software services, communication protocols, authentication logic, and update policies can be deployed and maintained throughout the operational lifecycle. This leads to a BMC in which key partners include the OEM, the SDV platform provider, middleware and security suppliers, integration partners, and update management actors.

The key activities for this case follow the control structure in the software update loop: software architecture definition, protocol configuration, authentication management, update orchestration, rollback handling, and release validation. The corresponding key resources include the OTA platform, the software toolchain, configuration-management capability, cyber-governance processes, and the engineering capacity needed to maintain integration quality across the supply chain.

The value proposition for this case is grounded in the opportunities revealed when software-related assumptions are challenged. Gaps in protocol stability, authentication consistency, update control, and rollback resilience point towards commercial opportunities in secure OTA delivery, update-governance services, authentication and access-management support, and platform integration assurance. These outputs are highly relevant to the project scope because they illustrate how the transition to SDVs changes the basis of value creation: commercial success no longer depends only on the initial vehicle sale, but also on the ability to maintain, update and assure software-enabled functionality throughout the vehicle lifecycle.

Key Partners
- OEMs, Tier-2 OS and middleware suppliers, AUTOSAR module suppliers, cybersecurity and update-component providers, cloud and DevOps providers, connectivity providers, validation labs, and regulators.
- OS vendors, middleware and AUTOSAR module suppliers, diagnostic-interface suppliers, network and gateway suppliers.
- OS and middleware modules, security libraries, update agents, protocol stacks, diagnostics interfaces, and integration toolchains.
- To accelerate release cycles, enable secure OTA deployment, increase software reuse, and improve cyber-compliance posture.

Key Activities
- API and service design, platform integration, release management, variant management, cybersecurity assurance, and rollback planning.
- Developer portal, OEM engineering interfaces, dealer diagnostic tools, OTA dashboards, and integration APIs that support delivery channels.
- Incident handling, release-note communication, service support, escalation management, software lifecycle governance, and cyber-response coordination.
- Platform licensing, managed OTA operations, service-level agreements, integration support, and software maintenance contracts.

Key Resources
- CI/CD pipeline, integration lab, telemetry and observability stack, and test automation assets.
- APIs, documentation, partner portal, OTA dashboard, and diagnostics interfaces.
- Support desk, ticketing, configuration database, security-response capability, and release-governance records.
- Deployment analytics and compliance evidence.

Value Propositions
- Faster secure feature deployment, reduced integration effort, better update resilience, reusable platform modules, and stronger cyber and software-update governance.
- Fragmented E/E integration, costly rework, failed or unsafe updates, unstable interfac-es, weak authentication, and slow time-to-feature.
- Platform stack, OTA update service, security and authentication module, integration toolkit, diagnostics package, and managed release operations.
- Reliable updates, cyber assurance, integra-tion speed, software reuse across variants, lower lifecycle cost, and maintainable architecture.

Customer Relationships
- Long-term technical partnership, clear governance, rapid incident response, and transparent release planning.
- Integration support, managed release planning, OTA opera-tions, security advisories, and defect escalation work-flows.
- Integrated with OEM engineering, cloud operations, cy-ber operations, dealer diagnostics, and supplier-release man-agement.
- High upfront cost for integration and assurance, then lower incremental cost as platform reuse and automation im-prove.

Channels
- Partner portal, integration workshops, OTA dashboards, service tooling, and diagnostics channels.
- Direct OEM programmes, engineering teams, supplier integration channels, and managed release operations.
- Structured partner APIs, documentation portal, automated CI integration, and OTA dashboards.
- Reusable platform modules, self-service documentation, and automated validation and deployment channels.
- Release gates, cyber-response processes, and service diagnostics workflows.

Customer Segments
- OEMs, Tier-1 integrators,and obility fleets needing OTA governance.
- OEMs launching scalable SDV architectures and managing large installed vehicle fleets are the most important customers.

Cost Structure
- Platform engineering, cybersecurity assurance, CI/CD and cloud operations, validation, support, incident response, and compliance costs.
- Architecture team, integration lab, security stack, observability tooling, and release-management platform.
- Integration, validation, rollback testing, vulnerability management, release operations, and issue triage are most expensive.
- Value-driven at launch, then increasingly balanced by reuse efficiency and scale economics as more programmes share the platform.

Revenue Streams
- Lower integration risk, safe OTA deployment, faster time-to-feature, and compliant cyber and software-update operations.
- Licence fees, validation programmes, support contracts, and aftersales update campaigns.
- Milestone-based engineering contracts, annual licences, support retainers, and programme-specific deployment fees.
- Multi-year platform licence, per-vehicle deployment fee, managed service subscription, or tiered support package.
- Platform licence, per-vehicle software fee, OTA operations subscription, cyber-support contract, and integration services revenue.
- Annual licence, per-programme integration fee, per-vehicle royalty, and usage-based OTA or support service tiers.

Figure 15: Synthesis of the Systems-Thinking Approach into a Business Model Canvas for the Secure Software Platform Integration and Update Assurance case study

Case Study 3: SDV- Insurance pricing case study

The Business Model Canvas presented in Figure 16 is derived from the systems thinking approach applied to SDV-enabled insurance pricing. By modelling the control structure, stakeholder interactions, and closed loops (control actions and feedback), the approach identifies how pricing decisions depend on real-time data flows between OEMs, insurers, customers, and other ecosystem actors. This leads to a business model where key partners, activities, and resources are defined by the need to access, process, and act on behavioural and vehicle data.

The explicit identification of assumptions shapes the core elements of the canvas, particularly the value proposition, customer relationships, and channels. Behaviour-based pricing, transparency, and safety incentives arise from the assumption that customer data can be reliably captured and used for risk assessment. At the same time, continuous feedback from customers through driving behaviour enables more personalised interactions and embedded digital delivery through SDV platforms. As a result, both value creation and customer engagement become data-driven and dynamically adjusted.

Finally, the approach reveals that revenue streams and cost structures are tightly linked to system interaction. Each element of the canvas is underpinned by assumptions regarding data access, customer behaviour, and ecosystem interaction.

Overall, the findings from these three case studies demonstrate how the systems thinking approach supports more informed and coordinated decision-making for the deployment of SDV in the UK. By explicitly identifying all the involved stakeholder, their roles, and interactions, the analysis highlighted where current practices may limit the value creation. Translating these insights into BMC makes the results actionable. It clarifies how value can be created and captured across the ecosystem, what capabilities need to be strengthened, and where collaboration between stakeholders can be critical. This helps different stakeholders involved in the SDV ecosystem, including OEMs, insurers, and regulators, to prioritise efforts that improve and support growth opportunities of the current SDV ecosystem.

Key Partners
- OEMs / SDV integrators, telecom providers, fleet and mobility operators, data analytics providers, claims and repair networks, public infrastructure stakeholders.
- Vehicle data providers(FOC), connectivity providers, claims support providers(dealers).
- Real-time vehicle and driving data, connectivity services, traffic and road-context data, claims support infrastructure.
- Faster integration into SDV ecosystems, improved pricing accuracy, better claims efficiency.

Key Activities
- Customer satisfaction and behaviour, SDV risk modelling, dynamic pricing, underwriting, claims assessment, fraud detection.
- Mobile and web delivery(OTA), fleet account support, digital claims handling.
- Customer support, claims handling, driver feedback, consent and privacy management.
- Premium optimisation, pricing analytics, usage-based billing, contract management.

Key Resources
- High-quality driving behaviour data, secure data infrastructure, consent management systems.
- SDV integrated interfaces, mobile apps, online portals, APIs.
- Claims platforms, support systems.
- Pricing engines, customer risk segmentation tools, financial analytics, loss-ratio monitoring.

Value Propositions
- Fairer insurance based on actual driving behaviour, tailored SDV insurance products, safer driving incentives, faster and more transparent claims handling.
- Traditional insurance does not reflect SDV risk, lack of tailored products for SDV users, limited pricing transparency, weak adaptation to fleet and connected mobility use cases.
- Usage-based SDV insurance, fleet SDV insurance, real-time driver feedback, digital claims support
- Fair pricing, transparency, flexibility, trust, risk reduction, faster service.

Customer Relationships
- Transparent, trustworthy, digitally accessible, responsive during claims, personalised through behavioural insights.
- Digital self-service, policy and claims support, customer notifications, risk feedback, customer education.
- Integrated with OEM channels, linked to pricing and claims systems, supported by data consent and privacy controls.
- Moderate to high initially due to integration and support setup, then lower at scale through automation.

Channels
- In-vehicle interfaces, OEM mobile apps, insurer app and portal, fleet management platforms.
- Insurer digital touchpoints.
- Mobile interfaces, fleet dashboards.
- Embedded partner channels, automated onboarding and claims channels.
- Insurance offered at purchase or activation, policy and consent managed through SDV apps, claims support.

Customer Segments
- Private SDV users, early adopters of connected and automated vehicle services, fleet operators, commercial customers managing SDV-enabled vehicles.
- Early SDV users willing to share driving data, fleet operators seeking usage-based pricing.

Cost Structure
- Claims costs, data infrastructure, cloud processing, model development, OEM integration, compliance, customer support.
- Data infrastructure, analytics capabilities, OEM integration.
- Data processing, governance, claims handling, integration and deployment.
- Value-driven initially, with increasing pressure for cost efficiency as scale grows.

Revenue Streams
- Fairer behaviour-based pricing, tailored SDV coverage, faster claims service.
- Traditional motor insurance premiums, fleet insurance contracts, static annual or monthly products.
- Annual premiums, monthly premiums, fleet contracts.
- Flexible monthly pricing, usage-based pricing, behaviour-linked premiums, bundled pricing through OEM or fleet platforms.
- Usage-based premiums, subscription-style coverage, fleet insurance contracts.
- Dynamic pricing, customer behaviour-based pricing, product-feature-based pricing.

Figure 16: Business Model Canvas for the SDV-enabled insurance pricing case study

Section 3: Conclusion: Prioritisation and focus on the road ahead

Summary of the opportunity and motivation

The term 'Software Defined Vehicle' (SDV) is becoming increasingly discussed in the automotive space. Emerging through a sectoral need to understand where the automotive and mobility opportunities are in emerging technology capabilities such as AI and computation. However, given the hype around emerging technologies it's not always clear what SDV means. We see instances of emerging capabilities in the automotive supply chain being referred to as SDV's, such as operating systems. Original Vehicle Manufacturers (OEM's) refer to future vehicle releases as being software defined. Emerging technologies such as self-driving and advanced driving assistance system (ADAS) rely heavily on state-of-the-art software and hardware. However, a precise understanding of the software defined vehicle ecosystem, its stakeholders and their associated capabilities, is missing.

As a result, when taking the abstract concept of the SDV to a co-create implementation level we see challenges emerging. Traditional automotive players can be out of sync with new supply chain entrants, slowing down integration to their existing product lines. Investors are unable to build robust certainty around new revenue streams holding back investment. Policy makers lack the data to design enabling policy interventions. Manufacturers are unable to make 'build or buy' decisions for new components. This all leads to the promise of new mobility products and services being constrained, and end-users become confused about true capabilities and limitations of technology.

These challenges lead to a key question for progressing the UK ecosystem that we address in this report:

What is the complete system of stakeholders and capability needed to build end-to-end SDV capability? For each stakeholder to realise new revenue streams what capabilities do they need? What partners do each need? How will cost structures and business models shift? How do incumbent and new entrants need to adapt to one another and the regulatory environment?

From the technical literature, a software-defined vehicle (SDV) is not a single technology but a convergence of architecture, lifecycle/ business model shifts, and security/ safety perspectives. In the literature we find evidence that there is a divergence in conceptualising what an SDV is, especially between research and industry stakeholders. We therefore provide our own definition of an SDV for the purpose of this report, drawing on established definitions from industrial and research sources as:

A vehicle that's engineering and operations are centralised through software across both safety-critical and non-safety-critical attributes: the software first vehicle.

Summary of the challenges faced in realising the SDV vision

Analyses of the evidence on SDV ecosystems emphasise shifting power and roles among OEMs, Tier1 suppliers, ICT/cloud providers, and new software platform players. As software and services become the main differentiators, control of operating systems, data platforms, and user experience becomes central. These 'power' structures and their shifting nature under conditions of technology transition are essential context in which to analyse the industry. However nuanced and specific challenges are emerging which we find to include:

- How novel service offerings and their **requirements ripple down the systems-engineering pipeline**, often with multiple hand offs between supply chain partners with divergence norms and cultures (i.e. incumbent OEM supply chain vs software developers) to realise System and Architecture CoDesign (silicon-to-system)
- **Realising continuous integration /continuous development (CI/CD) pipelines** where methods and tools are well established across software development industries, adaption to SDV specifically raises challenges that include ensuring safety when updates affect distributed components, integrating regulatory and regional constraints into deployment logic, and coordinating multiple organisations' codebases and toolchains
- **Prioritising safety/ security critical performance** where SDVs are expected to host outsourced applications and continuous OTA updates while still satisfying safety regulations
- **Insurance liability and risk:** Shifts from driver to system/manufacturer makes traditional driver-centric risk models inadequate; insurers must consider system capabilities, software, and human–machine interaction. Multi-party liability and burden of proof (driver vs OEM vs software supplier) complicate the ability to effectively manage risk.
- **Knowledge transfer and skills:** due to SDVs fast, iterative software cycles traditional development and delivery models often struggle to adapt to the iterative demand of new automotive products, and that the transformation of enterprise capability faces multiple challenges
- **Data sharing and consumer consent:** From a fleet operations centre perspective, this will be quite important. As more issues are addressed through OTA SW updates (and not HW recalls), there is greater reliance on customers to agree to share their vehicle data

Summary of the steps required to build global competitive advantage

National advantage in an emerging technology sector rarely stands alone. Wide scale technology shifts (such as to AI, often referred to as general purpose technologies [GPT]) must work in tandem with existing, competitive manufacturing and services bases. Matching the right blend of public-private investment at the appropriate stage of the development cycle is an important consideration. Evidence from strategic emerging enterprises show that R&D investment is already a strong predictor of later highquality performance; early underinvestment is difficult to reverse.

At the firm level, sustained R&D remains the central quantitative driver of highquality development in the growth stage, supporting continuous product reinvention and longrun innovation capabilities. The implication for advanced economies is that "marketonly" funding models tend to underprovide the most transformative technologies; public instruments must deliberately target highrisk, highleverage core technologies.

To facilitate the interfaces challenges identified at a technical level and to promote the right kind of 'blended investment' we find in the evidence base that open platforms and digital ecosystems have become key levers for scaling emerging technologies. This addresses the identified challenges of 'reorganisation' required within the SDV context among diverse stakeholders, including incumbents, new entrants, adjacent general-purpose technologies, finance, insurance, data, maintenance and ultimately the user/ consumers, to realise a globally competitive position.

Analysis of historic industries, including communication infrastructure, aerospace supply chain integration, mobile handsets and app stores, we identify a range of attributes required of a successfully safety-critical platform/ ecosystem in the literature to include:

- Upstream **(pre product sales) capability focus maximises value capture** and increases the chances of anchoring capabilities over longer periods of time
- There is **not universally superior "open" or "closed" platform model** with research findings suggesting decision rules to calibrate openness by context, rather than prescribing a fixed model.
- **Influential orchestrators (usually consumer facing stakeholders) act as platform sponsors**, setting technical standards and ensuring interoperability, while enabling diverse partners to co-create services and products.
- **Governance and trust are critical in a safety-critical context:** standardised information and generic guidelines were insufficient, and progress depended on more tailored engagement and clear rules about participation, evaluation, and follow-up
- In one example **the "open" element is not free access but orchestrated participation of multiple partners** around shared performance contracts and standardised technical interfaces, enabling continuous improvement and incremental innovation in both hardware and services.

We can see the need to orchestrate skills, supply chains, IP, and safety while accelerating innovation and growth. We can see that across sectors, platform sponsors act as orchestrators, structuring access, standards, and governance to balance openness with control and risk management.

Where products and services are increasingly safety-critical and/ or have deep complexity of integration between stakeholders a recurring pattern for platform sponsors to have to carefully calibrate openness, providing broad access and standardised interfaces while retaining enough control to manage quality, safety, and strategic direction is seen.

Taken together, these cases suggest that open platforms enable industry growth and innovation not simply by being "open," but by deliberately configuring access, standards, governance, and incentives around the specific technological, regulatory, and risk characteristics of each industry.

Platform requirements established from systems thinking

Building on these findings, we use the four-step systems thinking process to move from case study analysis to platform-level requirements for an SDV ecosystem specifically. First, each use case was examined through the systems thinking lens to identify the actors, assumptions, and potential constraints shaping SDV deployment. Second, two complementary control structures were modelled to capture the system at different levels. The first control structure represents the

Reaching commercial viability (R&D) control structure, including the activities required before SDV-enabled services are released into real-world operation. This includes system design, software development, data governance definition, interface specification, safety and cybersecurity assurance, compliance preparation, validation, and stakeholder approval. This phase defines the system boundary around the actors and activities needed to prepare SDV services for deployment, which is represented in the second control structure Post-Deployment (Operational), where SDV-enabled services operate in the field and continue to generate data, feedback, updates, incidents, claims, service requests, and evidence for continuous assurance. The second phase expands the boundary to include operational actors and feedback sources, such as end-to-end customers and data service providers.

Together, the two structures illustrate the breadth of the SDV system and show that deployment cannot be understood only through the vehicle, the software or the OEM. It must be understood as a continuing socio-technical system involving technical, commercial, regulatory, and user-facing interactions.

The insurance, OTA updates, and battery health case studies show that SDV deployment depends on a shared platform, including trusted data exchange, standardised interfaces, software update governance, cybersecurity, user consent, and compliance evidence. Therefore, the systems thinking approach not only identifies risks and opportunities, but it also provides a structured basis for defining architecture for an open platform.

The proposed open platform would act as a shared ecosystem layer connecting OEMs, suppliers, insurers, fleet operators, infrastructure actors, service providers, regulators, and users.

Platform requirements are presented as shown in Table 1:

Category	Platform requirements
Functional requirements	▪ Provide controlled access to vehicle data for approved services, such as insurance, OTA update, FOC, and battery monitoring. ▪ Support standardised data formats. ▪ Provide APIs for OEMs, suppliers, insurers, fleet operators, service providers, and regulators. ▪ Support OTA update status, validation, and rollback history. ▪ Provide battery health analytics and charging behaviour monitoring. ▪ Provide a dashboard to different stakeholders, including OEMs, insurers, fleets, regulators, and users. ▪ Maintain audit for data access, software updates, consent changes, and compliance evidence. The open SDV platform must provide the core functions needed to support SDV services across the UK ecosystem. These functions include trusted vehicle data access, OTA support, battery health monitoring, insurance analytics, audit trails, and stakeholder-specific service interfaces.
Safety and assurance requirements	▪ Support traceability from hazards, assumptions, and deviations. ▪ Record safety-relevant events, update failures, degraded system states, and service interruptions. ▪ Support data collection for safety assessment and regulatory review. ▪ Define clear escalation paths when platform data indicates risk, such as failed OTA deployment or repeated claims events. The platform must support safety assurance across SDV lifecycle. This means it should capture hazards, incident reports, and escalation paths. The purpose is to make the platform not only for commercial services, but also for safety assessment, regulatory review, and continuous integration /continuous development (CI/CD).
Cybersecurity requirements	▪ Support secure software update delivery, validation, and rollback. ▪ Provide vulnerability reporting and incident response processes. ▪ Implement identity and access management for all actors. The platform must mitigate cybersecurity hazards, which include secure software delivery, vulnerability management, incident response, secure API, authentication, authorisation, audit, and protection of sensitive vehicle and user data.
Data governance requirements	▪ Define data ownership, access rights, and retention periods. ▪ Involve user consent. ▪ Classify and map data to the corresponding actor. ▪ Provide data quality indicators, such as completeness and accuracy. The platform must define how data is collected, processed, accessed, shared, stored, analysed, and validated. This includes data ownership, user consent, access rights, retention rules, data quality, and compliance reporting.
Interoperability requirements	▪ Allow integration with OEM platforms, tier 1, tier 2 suppliers, cloud providers, insurers, charging operators and dealers. ▪ Unify vehicle data definitions. The platform must allow different stakeholders and technical systems to work together. This requires open APIs and common data definitions.
Business and ecosystem requirements	▪ Define commercial rules for data access, revenue sharing, licensing, and service subscriptions. The platform must include a governance and business model that allows multiple stakeholders to participate. This includes service onboarding, approval and certification, revenue sharing, cost visibility, and long-term maintenance responsibilities.

Table 1: Recommendations for developing an enabling open SDV platform in the UK

Strategic attributes of priority in developing a platform ecosystem

Building on these requirements, recommendations translate the technical and operational needs of the open SDV platform into practical actions for UK implementation. The requirements identify the capabilities the platform must provide, including functional services, safety assurance, cybersecurity, data governance, and ecosystem coordination. The recommendations then set out how these capabilities can be organised, governed, tested, scaled, and sustained across stakeholders.

Develop a shared requirements register: The findings from the report should be converted into requirements register covering functional, safety, cybersecurity, data, interoperability, commercial, and user-trust requirements. This register should become the starting point for platform design and should be updated as new use cases are added.

Build the platform around open interfaces and common data models: The platform should adopt standardised data definitions so that services can be reused across different vehicles, fleets, and organisations.

Treat assurance as a continuous lifecycle activity: Safety and compliance evidence should not be collected only before deployment. The platform should support continuous assurance through monitoring, updating records, diagnostic data, incident reporting, and operational feedback.

Create a certification and onboarding process for third-party services: The platform should include a controlled process for approving new services before they access vehicle data or interact with vehicles.

Build public trust into the platform design: Users should be able to understand what data is collected, how it is used, who accesses it, and how it affects services such as insurance pricing, battery-health assessment, warranty decisions, and vehicle updates. This transparency is essential for public acceptance of SDV-enabled services.

Develop SDV skills, training, and capability-building programmes: the UK should develop targeted skills and training programmes to support the open SDV platform. Training should be aimed not only at engineers, but also at regulators, insurers, fleet operators, service providers, and public-sector decision-makers.

Accelerate capability transfer: The UK should actively accelerate the transfer of capability from adjacent industries, including AI, cloud computing, cybersecurity, data platforms, telecommunications, and digital health, into automotive SDV applications.

By organising these requirements into a set of recommendations, the report provides a clear signpost for policymakers, regulators, industry stakeholders, and researchers. The proposed open platform can therefore support safe SDV deployment, reduce integration barriers, enable trusted data use, and build the shared capability needed for the UK to scale SDV services responsibly and effectively.

Next steps to implement the findings of this report: building a platform business case

Develop a detailed and compelling business case for the establishment of a UK centric SDV platform:

- Create a proof of concept (PoC) of the core assets recommended in the two prior sections *Platform requirements established from systems thinking and Strategic attributes of priority in developing a platform ecosystem* for detailed stakeholder testing and feedback i.e. an initial requirement register, proposed open data set library, certification and on-board processes etc.

- Comparative analysis of existing SDV platforms nationally and internationally (such as The Eclipse Foundation) to establish a detailed implementation strategy that addresses functional gaps or weaknesses in existing initiatives and does not compete where existing initiatives are fit for purpose

- Through PoC testing identify sustainable incentive mechanisms to validate credible stakeholder contribution to the platform (not just lip service). This will require continuous identification of stakeholder 'pain points' and effective responses to those challenges. The 4-step systems thinking process used within this study is intentionally designed to a) monitor assumptions enabling dynamic application over time and b) systematically explore deeper levels of abstraction for individual stakeholders leading to more accurate identification of 'pain points' to enable this. Therefore, the systems thinking assets (control structures) presented in this report should be leveraged and developed to capture further granularity of detail.

- Establish a blended and progressive investment model that exploits the identified incentive mechanisms,

  - Early stage: Likely a Government heavy funding model to establish the early capability requirements recommended in this report, matched by high degrees of in-kind industry contribution (cash contribution at this high-risk stage from industry is unlikely). This stage should include a mechanism for engaging private funding stakeholders to ensure long term strategic direction towards investable outcomes

  - Development stage: Map a credible path towards increasing degrees of industrial investment in the platform realised through revenue growth, supply chain strengthening, export growth and capital investment. A critical component of this strategy should be the creation of platform orchestrators who are often consumer facing and have the influence and tools to guide Governance and long-term management of the platform system – reflecting findings in this report.

- Draw up plans for a central co-ordination body which governs the technical and strategy elements of the system – with a physical HQ bridging gaps between disparate stakeholders/ regional capabilities i.e. software capability in Cambridge/ Kings Cross with the automotive corridor capabilities through the midlands.

- Develop a programme of curated engagements that bridge stakeholder gaps in the system, designed around the pain points/ incentivisation findings. This should include the buildings of effective cultures such as continuous safety and security, relationships that enable accelerated automotive adoption of general-purpose technologies, and relationships that enable scaled capital investments.

Appendix

Statement on the Use of Artificial Intelligence in This Report

This literature review and research report has been prepared in full compliance with the Artificial Intelligence policies and guidance provided by:

- The University of Warwick – AI in Research Guidance https://warwick.ac.uk/services/ris/research-integrity/airesearch/
- Imperial College London – Generative AI Guidance https://www.imperial.ac.uk/admin-services/library/learning-support/generative-ai-guidance/
- The Russell Group – Principles on the Use of Generative AI in Education https://www.russellgroup.ac.uk/media/6100/rg_principles_final.pdf

In line with these policies, this report follows the shared principles of **ethical, transparent, and responsible use of Artificial Intelligence**. Specifically, it ensures that:

- **AI use is fully disclosed,** including the purpose and scope of any AI assistance
- **All AIgenerated outputs have been critically evaluated, and used only as supportive tools**

Any contributions made by AI tools are documented and checked for accuracy, bias, and reliability, ensuring that the final content remains the author's own original, critically reviewed scholarly work.

Tools used in the creation of this report are for early-stage research, synthesis and drafting

Tools used are Microsoft Co-Pilot and Consensus.ai.

References

Becker, J., Sagar, M., & Pangercic, D. (2021). A Safety-Certified Vehicle OS to Enable Software-Defined Vehicles. *Proceedings*. https://doi.org/10.1007/978-3-658-34754-3_5

Bersosa, D., Ortis, A., & Heredero, C. (2013). Open Business Models in the Telecommunications Industry. **, 221-231. https://doi.org/10.4018/978-1-61350-341-6.ch013

Boudreau, K. (2010). Open Platform Strategies and Innovation: Granting Access vs. Devolving Control. *Manag. Sci.*, 56, 1849-1872. https://doi.org/10.1287/mnsc.1100.1215

Boudreau, K. (2010). Open Platform Strategies and Innovation: Granting Access vs. Devolving Control. *Manag. Sci.*, 56, 1849-1872. https://doi.org/10.1287/mnsc.1100.1215

Cenamor, J., & Frishammar, J. (2020). Openness in platform ecosystems: Innovation strategies for complementary products. *Research Policy*, 50, 104148. https://doi.org/10.1016/j.respol.2020.104148

Chun, Y., Hur, J., & Hwang, J. (2024). AI technology specialisation and national competitiveness. *PLOS ONE*, 19. https://doi.org/10.1371/journal.pone.0301091

Daiberl, C., Oks, S., Roth, A., Möslein, K., & Alter, S. (2019). Design principles for establishing a multi-sided open innovation platform: lessons learned from an action research study in the medical technology industry. *Electronic Markets*, 1-18. https://doi.org/10.1007/s12525-018-0325-2

Das, A., & Dey, S. (2021). Global manufacturing value networks: assessing the critical roles of platform ecosystems and Industry 4.0. *Journal of Manufacturing Technology Management*.https://doi.org/10.1108/jmtm-04-2020-0161

De Vincensi, M., Pes'e, M., Bodei, C., Matteucci, I., Brooks, R., Hasan, M., Saracino, A., Hamad, M., & Steinhorst, S. (2024). Contextualising Security and Privacy of Software-Defined Vehicles: State of the Art and Industry Perspectives. *ArXiv*, abs/2411.10612. https://doi.org/10.48550/arxiv.2411.10612

Eckhardt, J., Ciuchta, M., & Carpenter, M. (2018). Open innovation, information, and entrepreneurship within platform ecosystems. *Strategic Entrepreneurship Journal*. https://doi.org/10.1002/sej.1298

Goswami, P. (2024). The Software-defined Vehicle: Its Current Trajectory and Execution Challenges. **. https://doi.org/10.4271/epr2024027

Häckel, T., Meyer, P., Korf, F., & Schmidt, T. (2022). Secure Time-Sensitive Software-Defined Networking in Vehicles. *IEEE Transactions on Vehicular Technology*, 72, 35-51. https://doi.org/10.1109/tvt.2022.3202368

Han, S., He, Y., & Ding, Y. (2020). Enable an Open Software Defined Mobility Ecosystem through VEC-OF. 2020 *IEEE 20th International Conference on Software Quality, Reliability and Security Companion* (QRS-C), 229-236. https://doi.org/10.1109/qrs-c51114.2020.00046

Jiang, S. (2024). Vehicle E/E Architecture and Key Technologies Enabling Software-Defined Vehicle. *SAE Technical Paper Series*. https://doi.org/10.4271/2024-01-2035

Jovanovic, M., Engwall, M., & Jerbrant, A. (2016). Matching Service Offerings and Product Operations: A Key to Servitisation Success. *Research-Technology Management*, 59, 29 - 36. https://doi.org/10.1080/08956308.2016.1161403

Kaggwa, S., Akinwolemiwa, D., Dawodu, S., Uwaoma, P., Akindote, O., & Eloghosa, S. (2023). Digital transformation and economic development: A review of emerging technologies' impact on national economies. *World Journal of Advanced Research and Reviews*. https://doi.org/10.30574/wjarr.2023.20.3.2541

Khamis, A., & Goswami, P. (2025). Rethinking Vehicle Architecture Through Softwarisation and Servitisation. *IEEE Access*, 13, 126213-126226. https://doi.org/10.1109/access.2025.3588432

Klus, J. (2014). New and emerging technologies: a competitive edge for national success. *International Journal of Technology Management*. https://doi.org/10.1504/ijtm.1993.025787

Kuru, K. (2022). TrustFSDV: Framework for Building and Maintaining Trust in Self-Driving Vehicles. *IEEE Access*, 10, 82814-82833. https://doi.org/10.1109/access.2022.3196941

Liu, S., Shang, W., & Shao, F. (2022). Impact, Challenges and Prospect of Software-Defined Vehicles. *Automotive Innovation*, 5, 180 - 194. https://doi.org/10.1007/s42154-022-00179-s

Máté, B., Scheerer, M., Sieger, R., Denninger, O., & Henß, J. (2025). Software-Defined Vehicles: Bridging Industry and Research Perspectives. 2025 *IEEE 34th International Symposium on Industrial Electronics (ISIE)*, 1-6. https://doi.org/10.1109/isie62713.2025.11124637

Muchungu, A., & Mutua, J. (2024). Open Innovation Strategies and Organisation Performance of the Telecommunication Industry in Kenya. *European Journal of Business and Strategic Management*. https://doi.org/10.47604/ejbsm.2566

Narashiman, S., Venkat, A., Joshi, D., Sridhar, D., Rajesh, H., Sattva, S., Aniruddha, S., Jayanth, B., Manjunath, V., & Ragavendiran, N. (2024). Chiplets on Wheels: Review Paper on Holistic Chiplet Solutions for Autonomous Vehicles. *ArXiv*, abs/2406.00182. https://doi.org/10.48550/arxiv.2406.00182

Ober, J. (2022). Open Innovation in the ICT Industry: Substantiation from Poland. *Journal of Open Innovation: Technology, Market, and Complexity*. https://doi.org/10.3390/joitmc8030158

Ohlsen, J. (2022). The software-defined Vehicle Is Overwhelming the Automotive Industry. *ATSelectronics worldwide*, 17, 56 - 56. https://doi.org/10.1007/s38314-022-0783-3

Ondrus, J., Gannamaneni, A., & Lyytinen, K. (2015). The impact of openness on the market potential of multi-sided platforms: a case study of mobile payment platforms. *Journal of Information Technology*, 30, 260-275. https://doi.org/10.1057/jit.2015.7

Pan, F., Rickert, M., Bets, T., Wen, L., Lin, J., Petrovic, N., Lienkamp, M., & Knoll, A. (2024). Toward Software-Defined Vehicles: From Model-Based Engineering to Virtualisation-Based Deployment. I*EEE Access*, 12, 192127-192145. https://doi.org/10.1109/access.2024.3512002

Schleicher, C. (2021). Paving the way for the "Software Defined Vehicle". *ELIV 2021*. https://doi.org/10.51202/9783181023846-273

Sghaier, K., Hammi, B., Gharbi, G., Merdrignac, P., Parrend, P., & Verna, D. (2025). Advancing Security in Software-Defined Vehicles: A Comprehensive Survey and Taxonomy. *ArXiv*, abs/2510.09675. https://doi.org/10.48550/arxiv.2510.09675

Teixeira, P., Raposo, D., Lopes, R., & Sargento, S. (2024). Deterministic and Reliable Software-Defined Vehicles: key building blocks, challenges, and vision.

Wang, J., Guo, B., Wang, X., & Lou, S. (2020). Closed or open platform? the nature of platform and a qualitative comparative analysis of the performance effect of platform openness. *Electronic Commerce Research and Applications*, 44, 101007 - 101007. https://doi.org/10.1016/j.elerap.2020.101007

Weiss, M., Navalgund, A., Stümpfle, J., Dettinger, F., & Weyrich, M. (2025). An OpenSource CI/CD Pipeline for Variant-Rich Software-Defined Vehicles. 2025 *IEEE International Automated Vehicle Validation Conference* (IAVVC), 1-6. https://doi.org/10.1109/iavvc61942.2025.11219546

Wolschke, C., Sangchoolie, B., Simon, J., Marksteiner, S., Braun, T., & Hamasaryan, H. (2021). SaSeVAL: A Safety/Security-Aware Approach for Validation of Safety-Critical Systems. *2021 51st Annual IEEE/IFIP International Conference on Dependable Systems and Networks Workshops (DSN-W)*, 27-34. https://doi.org/10.1109/dsn-w52860.2021.00016

Yun, J., & Liu, S. (2019). Micro- and Macro-Dynamics of Open Innovation with a Quadruple-Helix Model. *Sustainability*. https://doi.org/10.3390/su11123301

Shao, F., Song, H., & Liu, S. (2022). Identification and Analysis of Key Technical Elements and Prospects for Software-Defined Vehicles. *SAE Technical Paper Series*. https://doi.org/10.4271/2022-01-7002

Asheim, B.T. and Coenen, L. (2005) 'Knowledge bases and regional innovation systems: Comparing Nordic clusters', *Research Policy*, 34(8), pp. 1173–1190. Available at: https://doi.org/10.1016/j.respol.2005.03.013.

Cooke, P. (2001) 'Regional Innovation Systems, Clusters, and the Knowledge Economy', *Industrial and Corporate Change*, 10(4), pp. 945–974. Available at: https://doi.org/10.1093/icc/10.4.945.

El Badaoui, H. *et al.* (2026) 'Introducing a Novel System Engineering Framework for the Safe Deployment of Software Defined-Vehicles', S*ymposium on International Automotive Technology* (2026). SAE Technical Paper.

Elizebeth, M.J. *et al.* (2025) 'Safety Analysis of eVTOL Operations based on STPA', *arXiv preprint arXiv:2510.09283* [Preprint].

Gaddy, B.E. *et al.* (2017) 'Venture Capital and Cleantech: The wrong model for energy innovation', *Energy Policy*, 102, pp. 385–395. Available at: https://doi.org/10.1016/j.enpol.2016.12.035.

Khastgir, S. et al. (2021) 'Systems approach to creating test scenarios for automated driving systems', *Reliability engineering & system safety*, 215, p. 107610.

Malerba, F. (2002) 'Sectoral systems of innovation and production', Research Policy, 31(2), pp. 247–264. https://doi.org/10.1016/S0048-7333(01)00139-1.

Osterwalder, A. and Pigneur, Y. (2013) *Business model generation: a handbook for visionaries, game changers, and challengers*. John Wiley & Sons.

Otto, S., Wlcek, M. and Wortmann, F. (2025) 'Towards Conceptualizing Software-Defined Vehicles: A Systematic Review and Future Research Avenues'.

Teece, D.J. (2010) 'Business models, business strategy and innovation', *Long range planning*, 43(2–3), pp. 172–194.

Tokas, S. and Owe, O. (2020) 'A formal framework for consent management', *International Conference on Formal Techniques for Distributed Objects, Components, and Systems*. Springer, pp. 169–186.

Vatankhah, S. *et al.* (2023) 'Understanding business model development through the lens of complexity theory: Enablers and barriers', *Journal of Business Research*, 155, p. 113350.

Widmer, T. (2016) *Assessing the strengths and limitations of Business Model Frameworks for Product Service Systems in the Circular Economy: Why Canvas and co. are not enough.*

Nanda, R. and Rhodes-Kropf, M., 2017. Financing risk and innovation. *Management science*, 63(4), pp.901-918.

Please cite:

El Badaoui H, Smith J., Khastgir S, (2026) The roadmap towards a Software Defined Vehicle UK centric platform: A systems thinking approach

DOI: https://doi.org/10.25560/131743