NEXT-LEVEL FLEET MANAGEMENT: HOW SLEEVE STREAMLINES REMOTE ACCESS AND BOOSTS DEVELOPMENT EFFICIENCY WITH EDGE-TO-CLOUD

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ABSTRACT

Managing a large fleet of test vehicles in modern automotive development is a complex and challenging task. Engineers must contend with physical prototypes spread across test sites, each filled with prototypical electronic control units (ECUs), data loggers and other development infrastructure. Gaining remote access to these in-vehicle devices is difficult, and many tasks still require an engineer to be physically present with the car. As a result, routine actions like deploying new software builds, updating configurations and firmware or retrieving logged data from vehicles are often inefficient. These traditional, manual processes do not scale well – for example, managing thousands of test cars with diverse prototype and development devices becomes cumbersome due to disparate multi-vendor interfaces and manual workflows. In practice, teams frequently resort to driving vehicles back to a garage or shipping equipment around, which introduces delays and operational overhead.

This inefficiency in current test fleet management not only slows down development cycles but also drives up cost. Time spent traveling to vehicles or waiting for data could be better used in analysis and development. Moreover, as automotive software development accelerates, the gap between rapid software iteration and slow, in-person hardware access is widening. There is a clear need for a solution that allows engineers to remotely access and manage physical test assets just as easily as they manage software – bridging the distance between developer, test fleet manager and vehicle. This whitepaper introduces Sleeve as that solution, showing how it enables seamless remote fleet device management for Cariad's testing operations. We will explore the challenges in the current process, detail Sleeve's technical approach (via an in-car Sleeve Dock and cloud-based Sleeve Hub), and demonstrate the improvements in efficiency, collaboration, and cost savings that result.

PROBLEM STATEMENT

Testing fleets are the lifeblood of automotive development, but they bring a host of pain points when it comes to device management and remote access. Below we outline the key challenges that engineers and managers face in the current process:

- **Complex Fleet and Device Management:** A single test vehicle can contain dozens of prototype devices – ECUs from different suppliers, custom development devices, and data loggers – each with its own software and interface. Managing these requires juggling multiple vendor-specific tools and connection methods. **There is no unified way to access all devices remotely**, so engineers spend considerable effort switching contexts and maintaining separate connections. This complexity makes location, remote access, OTA updates, and data retrieval cumbersome, as there's little standardization and many manual steps involved. **Simply put, there is a high overhead to just set up or connect to a given test car's devices.**

- **Firmware Updates and Software Changes**: Updating or debugging the software on components in a test car (for example, analyzing the traces of software components of an ECU or updating data logger configurations) **is often a labor-intensive process**. In many cases, the car either must be brought into a lab or service bay where an engineer connects a laptop via cable to perform the update or have the engineer present as passenger. Over-the-air (OTA) update and access mechanisms exist in isolation, but with prototype parts from different vendors, there's no cohesive OTA solution – meaning engineers might have to perform each update separately and manually. This results in slow rollout of new device firmware to the fleet and inconsistent software versions across vehicles at any given time. A minor update can thus consume hours of coordination, or be deferred and batch-processed infrequently, **delaying testing feedback**.

- **Data Retrieval and Logging**: Test drives generate enormous amounts of data (bus logs, sensor readings, video, etc.) that need to be collected for analysis. Currently, retrieving this data can be as low-tech as physically pulling a hard drive or SD card from the vehicle's data logger after a test, or attempting a remote download over unreliable connections. Both approaches are inefficient – physical retrieval causes delays (the car or storage device must travel back to the team), while ad-hoc remote connections (e.g. using a combination of cellular modem and consumer devices on a logger) are often slow and not user-friendly. **Critical insights can be stuck on a vehicle that's hundreds of kilometres away**. The lack of immediate remote data access hampers developers' ability to debug and iterate quickly on failures observed in the field.

- **Geographically Distributed Teams:** Automotive engineering teams today are distributed across multiple companies, sites and even countries. Collaborative work on the same vehicle or test scenario is hard when team members are not co-located. Often, different locations use slightly different tooling or setups, leading to inconsistent software tooling and methodologies in distributed teams and making it difficult to reproduce each other's results. An engineer in one location might not easily recreate a bug found by another team if they cannot access the exact same test bench or vehicle setup. On-boarding new team members or contractors is also slow because setting up the necessary environment (hardware + software) locally for them can be an immense task. All of this leads to late starts on testing, cascading project delays, and even **risks to Start of Production (SOP) timelines in extreme cases.**

- **Downtime and Logistical Inefficiencies:** When a problem arises on a test vehicle, often the quickest way to address it is to bring the vehicle "home" to headquarters or to dispatch an expert to the vehicle's location. Both options incur significant downtime. If a car has to return to a garage frequently for updates or troubleshooting, it's not being used for testing. If one team is using a particular test car or rig, another team might have to wait their turn – a clear bottleneck. In some cases, expensive tooling or license dongles might sit idle in one location while needed in another, just because of physical separation. These logistical hurdles translate directly into increased cost (idle time, travel expenses) and slower feedback loops in development.

In summary, **the current state of managing test fleets is fraught with inefficiencies**. Remote access to vehicles is limited and patchwork at best, resulting in slow update cycles and data latency. Coordination across teams and locations is suboptimal, and **valuable time is lost due to vehicles being out of operation or engineers being in transit**. These pain points underscore the need for a more effective approach – one that provides immediate, unified remote access to test vehicles and their devices, anywhere and anytime.

THE SLEEVE SOLUTION

Sleeve addresses the above challenges by providing a remote access platform tailored for connecting to embedded development infrastructure and devices, for the described use case, specifically in automotive test fleets. It essentially virtualizes the engineer's presence in the car. With Sleeve, geographically dispersed teams can work on a test vehicle as if they were sitting inside it, without leaving their desk. This is achieved through an innovative architecture that combines an in-car hardware unit (which also can be a data logger itself or a customer provisioned host) with a cloud-based management interface, creating a secure bridge between the vehicle and the engineer's web browser.

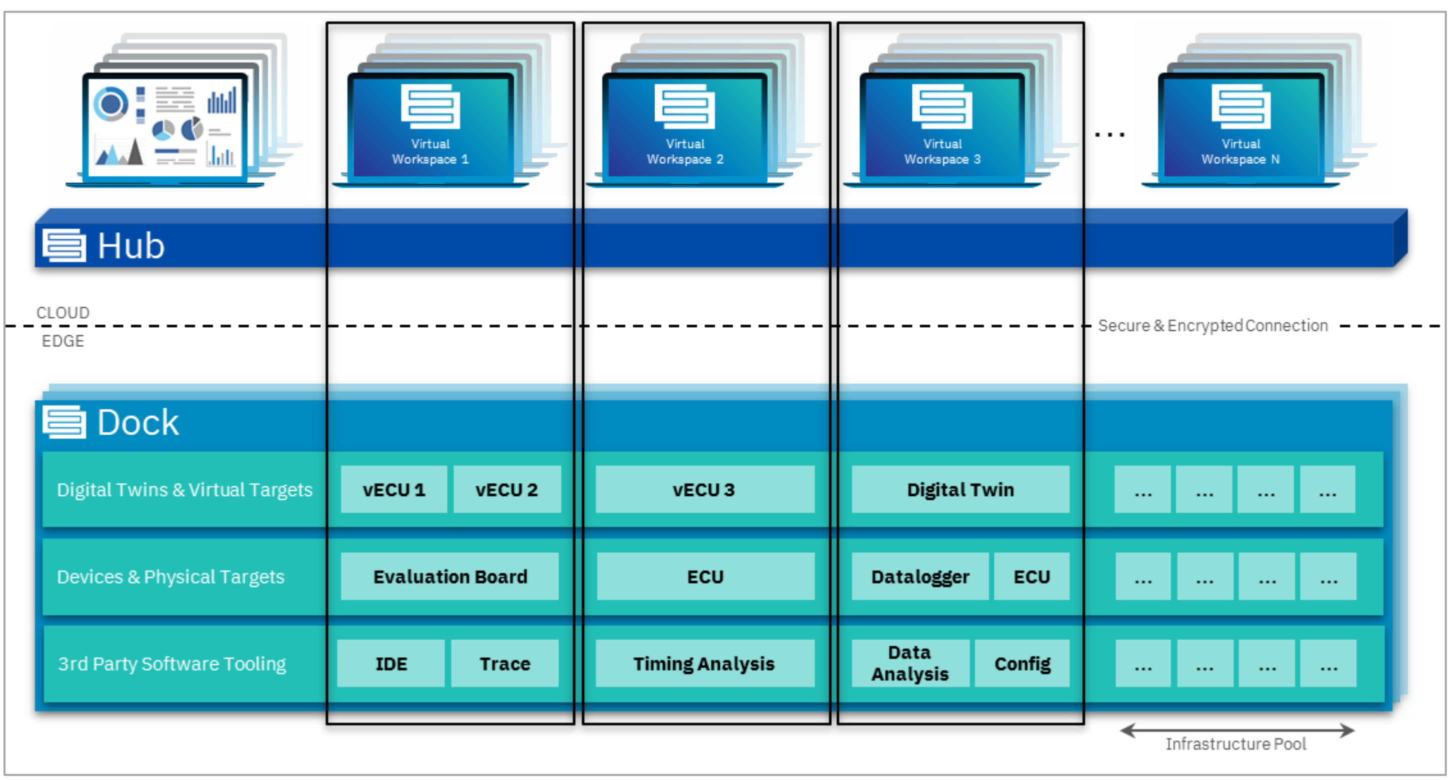

Figure 1 - Sleeve Cloud-Edge Continuum

Sleeve Architecture – Hub and Dock: The Sleeve system is composed of two integral components: **Sleeve Hub** and **Sleeve Dock**. Sleeve Hub is the cloud platform that acts as the entry point for users. It provides a web-based dashboard and interface where engineers and managers can see their fleet, launch sessions, and manage resources. Sleeve Dock is the edge component – a lightweight piece of software, installed on an a 5G enabled host installed in each test vehicle – which maintains connections to the in-car devices. Sleeve Hub and Dock communicate over the internet (tunnelled and encrypted) to form a secure pipeline from the user to the vehicle. This cloud–edge combination is designed to ensure swift and reliable communication with embedded devices, while remaining easy for users to access through a standard browser and OAuth2. In essence, Sleeve Dock in the car orchestrates the hardware connections and any edge application containers/virtual machines, and Sleeve Hub in the cloud orchestrates the user access and coordination.

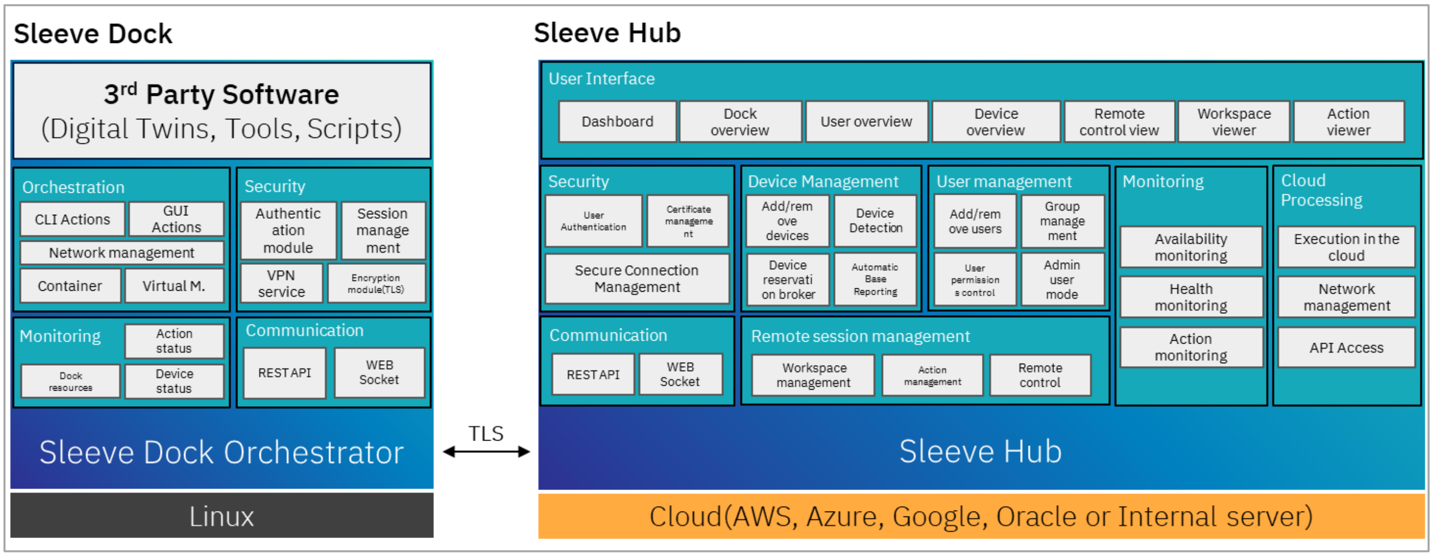

Figure 2 - Sleeve High-level Architecture

Remote Access "as if On-Site": Using Sleeve, an engineer can remotely access any onboard device or system through **an on-demand virtual workspace**. From the Sleeve Hub web interface, the user selects a vehicle (or a specific device in that vehicle) and launches a session. In the background, Sleeve Hub instructs the corresponding Sleeve Dock to open a connection to that device – for example, by starting a virtual machine that has the vendor's software tool for that device installed – and stream it to the user. The engineer's web browser then effectively becomes a window into the car. They can interact with instruments, run diagnostics, upload or download files, and even reboot hardware remotely. **Sleeve simplifies access to all devices, enabling management, localization and operation as if physically present in-car**. Data from those devices can be extracted, streamed to a data lake and viewed in real-time, or forwarded to other cloud applications for processing. This means tasks that once required a site visit – such as **updating device configurations or pulling data and logs from a data logger – can now be done from anywhere in the world with just a few clicks**. The platform also supports real-time telemetry and visualization through the browser, so an engineer can watch data streams live during a test drive, for instance, without being in the passenger seat. The use cases are endless.

Automotive-Grade Edge Hardware with 5G: A cornerstone of Sleeve's solution is the Sleeve Dock hardware host in each vehicle, which can be freely chosen. In this example it has been sourced by Sleeve for best performance and is built to automotive specifications. The Dock is essentially installed on this rugged embedded PC which interfaces with the vehicle's network (CAN/LIN/Ethernet, etc). Crucially, it has redundant 5G cellular connections for communication – typically using dual SIMs from different carriers – to ensure constant connectivity. Even as a test car moves through areas of patchy coverage, the 5G link and intelligent failover keep the secure tunnel to Sleeve Hub alive. The Dock host device is powered by the vehicle (supporting a wide input voltage range of ~9–60V DC and surviving automotive transients) and can handle extreme temperatures (industrial temperature range, e.g. –40°C to +70°C), meaning it **remains operational in cold winter tests or hot summer conditions**. It is configured to autostart with I/Os, e.g. with the vehicle's ignition (K15) and to safely shut down when the vehicle powers off, requiring minimal human intervention. In terms of size, the embedded device is compact, allowing unobtrusive installation in a car's trunk or electronics bay. Once installed, it provides a constant presence in the car that the remote engineers can tap into at any time. All communication between the Sleeve Dock and Sleeve Hub is secured via VPN and encryption, so proprietary test data and control commands are protected in transit (a critical requirement for automotive OEMs concerned with security). With this hardware in place, any authorized user can access the vehicle through a web browser from anywhere, with the Sleeve Dock effectively hosting their work environment at the edge.

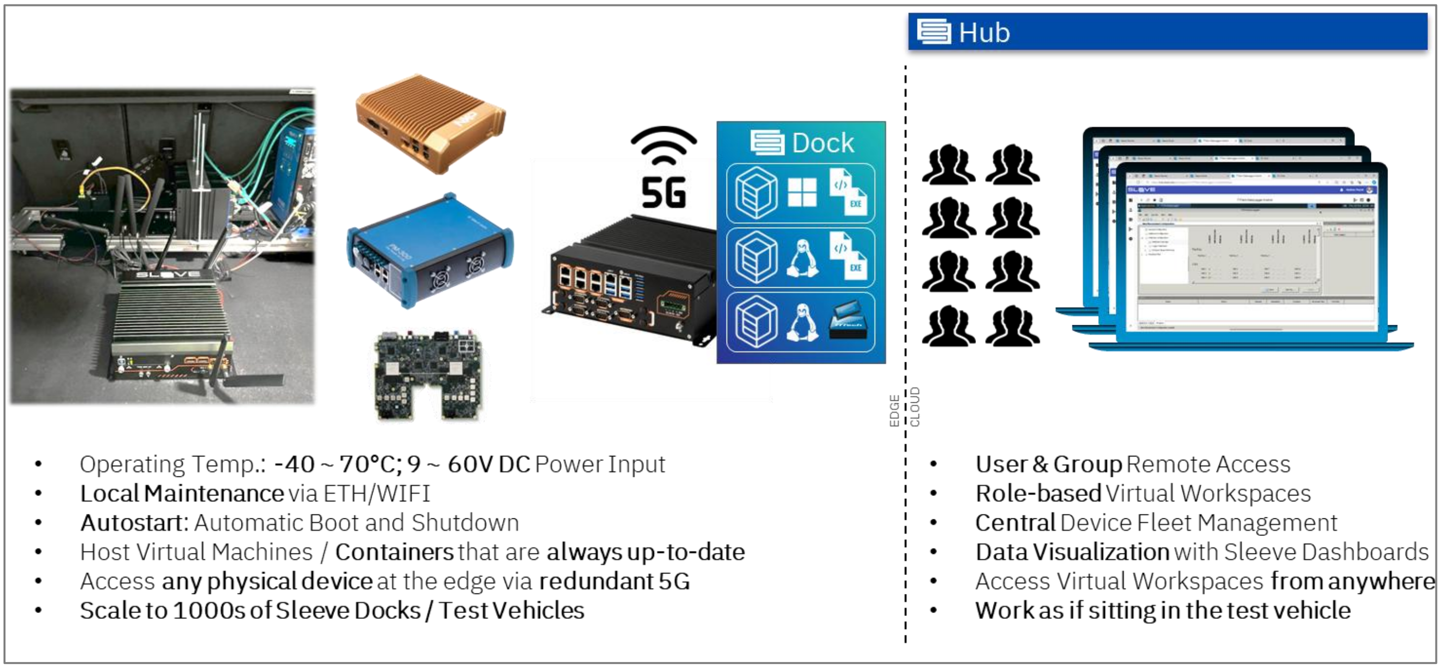

Figure 3 - Fleet Management Use Case with 5G

Unified Fleet Management: Beyond just point-to-point remote access, Sleeve provides overarching management capabilities for the entire fleet. Through Sleeve Hub's dashboard, managers can see the status and connectivity of each vehicle's Sleeve Dock (online/offline, network quality, etc.). They can assign vehicles to certain teams, roles or projects, and use a booking system to reserve exclusive access to a vehicle when running a particular test. This prevents conflicts (e.g. two people trying to unintentionally control the same target) and logs usage. User roles and permissions are integrated via the Hub's OAuth2 secure user management ‐ for example, a test technician might have access to run only specific authorized actions on the car, whereas a senior developer or administrator could get full root access to the system. All actions can be audited, which is important for safety and quality tracking. In short, **Sleeve not only makes remote access technically possible, it also makes it practical and organized at scale**. An entire fleet of vehicles can be monitored and managed centrally, with fine-grained control over who can do what on each car. This level of control and visibility is something that was sorely missing in the traditional approach of ad-hoc remote connections and isolated tools.

By combining a robust in-car gateway (Sleeve Dock) with an easy-to-use cloud interface (Sleeve Hub), Sleeve offers a holistic solution for remote fleet management. Engineers get on-demand access to the exact environment they need in each vehicle, and executives get better utilization of assets and a faster development cycle. The following sections will delve into how Sleeve is implemented under the hood and the tangible benefits it delivers in practice.

TECHNICAL IMPLEMENTATION

Underneath Sleeve's user-friendly facade is a sophisticated technical infrastructure that brings cloud flexibility to the edge of the automotive network. In this section, we outline how Sleeve is implemented in Cariad's test fleet environment, including its use of virtualization technology, integration with existing tools/scripts, and specific capabilities like remote data logger management.

Virtual Machines and Containers at the Edge: To accommodate the diverse software tools used in automotive testing, Sleeve's architecture supports running both Windows and Linux environments on the Sleeve Dock. Many automotive testing applications (for instance, certain ECU calibration tools or proprietary data logger software) are Windows-based, while a lot of scripting and automation is done with Linux utilities. Sleeve handles this by leveraging virtualization on the edge device. Windows-based tools run inside a virtual machine (VM) on the Sleeve Dock, whereas Linux tools run inside containers, using modern containerization technology. This approach allows the Sleeve Dock to mimic any required PC setup. For example, if an engineer needs to use a Vector CANalyzer (Windows application) to debug a CAN bus issue, they can launch a Windows VM on the Dock that has CANalyzer installed and connected to the car's CAN interface – all accessible through their browser. Conversely, if another task involves running a Python script on a Linux environment to process some sensor data, the Dock can spin up a lightweight container that has the script and necessary libraries pre-loaded. It even allows to host digital twins or shadowing modes with simulated ECUs at the edge. Both VMs and containers are managed by Sleeve Hub, which sends instructions to the Dock on what to start and connects the user's browser to the appropriate virtual workspace. **This hybrid virtualization strategy means any software stack can be executed on the remote vehicle on demand, providing extreme flexibility**. The virtualization is optimized for performance, taking advantage of the Sleeve Dock host's multi-core CPU and hardware virtualization support. In practice, users experience these remote sessions with minimal latency – e.g., a GUI application in the VM feels responsive thanks to efficient streaming. Importantly, each session (VM or container) runs in an isolated sandbox while being interconnected to share files between them - which protects the physical vehicle devices and the host system from any faults. When the user is done, the virtual workspace can be torn down or saved as needed. Sleeve also implements a system of container/VM templates – pre-configured images with the required software – so that launching a new workspace is fast and consistent across the fleet. These templates ensure that every engineer is using the correct software version and configuration, which eliminates the "it works on my machine" problem and drastically cuts down on setup time.

Integration of Proprietary Scripts and Workflows: Cariad's test teams have built up custom scripts and workflows over time – for example, scripts to automatically upload vehicle log files to a cloud server at the end of a test drive, or routines to reset certain devices before each test. Sleeve is designed to accommodate and enhance these existing workflows, not replace them outright. **On each Sleeve Dock, users can deploy their proprietary scripts into the Sleeve-managed environment** (inside a container or VM). These scripts can then be triggered remotely through the Sleeve Hub interface or set to trigger automatically on certain events. For instance, a data upload script can run every time a vehicle returns from a test run, pushing new log files to the central analysis server via the Dock's 5G connection. Before Sleeve, an engineer might have to manually connect to the vehicle after a test and run such a script or transfer files by hand. With Sleeve, it's seamless and can even be automated as part of the vehicle's shutdown procedure. This tight integration means that anything an engineer could do with a laptop physically plugged into the car can be encapsulated into a Sleeve action. Moreover, because these scripts run on the Sleeve Dock, they execute at the edge (next to the data source), which is efficient – large raw data files don't need to be piped over the network until the script has perhaps filtered or compressed them. Sleeve Dock has enough storage and compute to handle heavy data processing (CPU & GPU) locally. Another benefit is **centralized updates for these tools: when a proprietary script or a third-party tool gets an update, the new version can be deployed to all Sleeve Docks through the Sleeve Hub (for example, by updating the container template with Infrastructure-as-Code)** so every vehicle uses it from then on. This solves the earlier problem of script updates being time-intensive to roll out and sometimes getting missed on certain vehicles. In short, Sleeve acts as a distributed computing platform across the fleet, where custom automations and standard tools alike can be rolled out and executed uniformly.

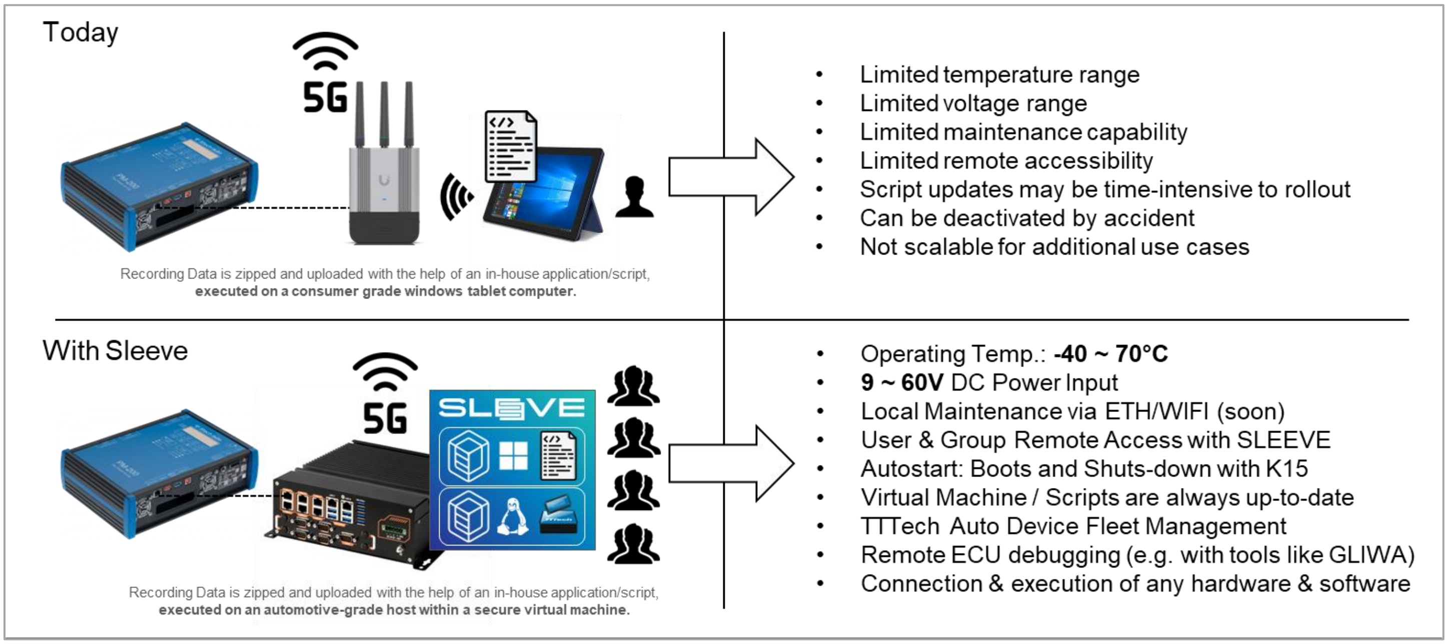

Figure 4 - Before/After Comparison

Managing Data Loggers and Other Test Equipment Remotely: A critical aspect of Sleeve's implementation is how it interfaces with specialized test equipment already present in vehicles. One notable example is the TTTech Auto PM200 and PM300/350 data logger units used in many of Cariad's test cars. These high-end loggers capture vehicle network data (CAN, Ethernet, Video etc.) during test drives for later analysis. Previously, to configure or offload data from these loggers, an engineer needed to physically access the device (either by connecting a laptop or removing the storage media). Sleeve simplifies this dramatically. The TTTech logger in the vehicle is connected to the Sleeve Dock (via an Ethernet or USB link), allowing Sleeve to expose the logger to the remote workspace. Through Sleeve, an engineer can launch the TTTech configuration software inside a virtual workspace and have it recognize the logger as if it were directly connected.

This means the engineer can start/stop logging, adjust capture settings, update firmware and download log files from the TTTech Auto device all through the browser, exactly as if they were in the car hooking up to the logger with the same look&feel. The Sleeve Dock effectively proxies the connection to the logger. All the rich capabilities of the logger becomes accessible remotely. Similarly, if the logger or other device outputs data files, those can be pulled into the Sleeve workspace and then streamed to cloud storage or analysis tools without anyone needing to touch the car.

Sleeve's virtualization also means multiple tools can run side by side – e.g. you could have the TTTech logging software running while simultaneously a GLIWA T1 is connected – enabling a holistic remote debugging session.. Any device that can connect to a PC can connect to the Sleeve

Dock and thereby be remotely controlled. This capability truly gives a remote user the feeling of sitting in the car with a full toolbox. One huge advantage can be remote ECU debugging.

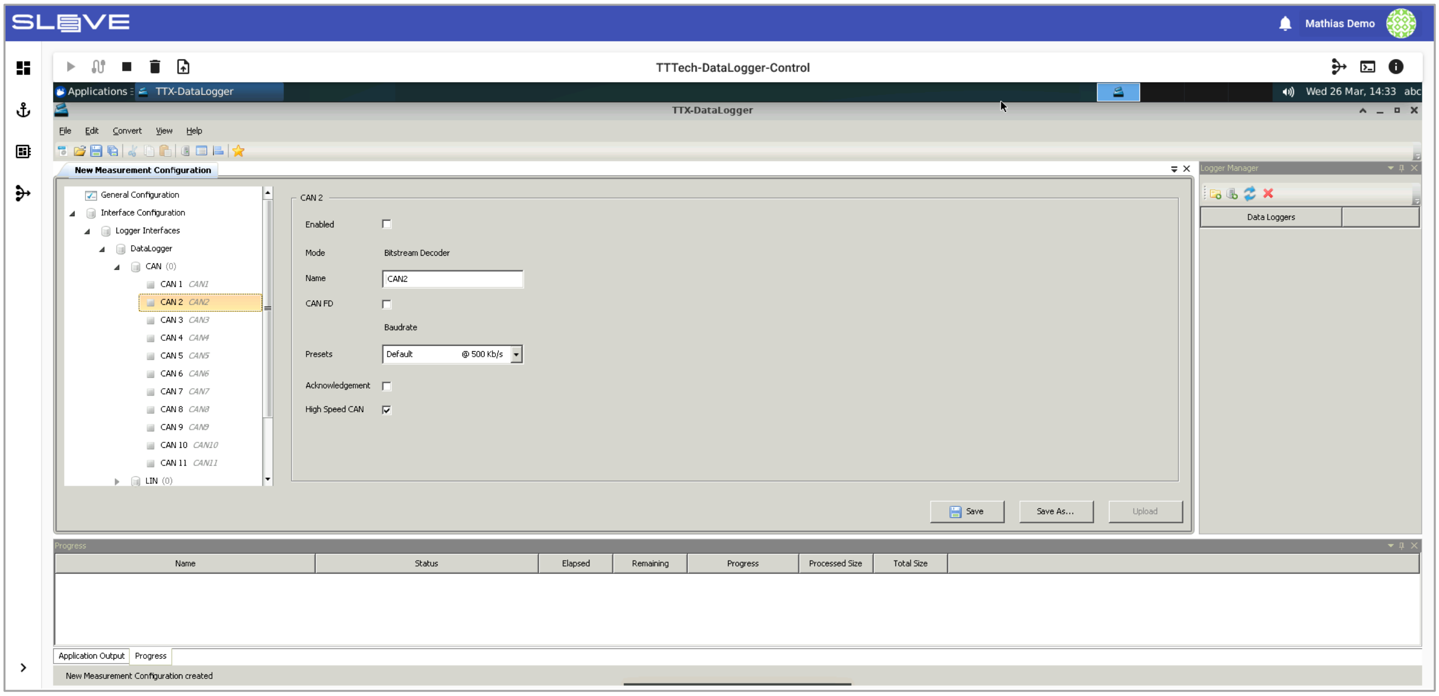

Figure 5 - TTTech Auto Datalogger tooling within Sleeve Hub

Using Sleeve, **developers can attach debuggers or performance analysis tools** (such as timing analysis software from **GLIWA**) to an ECU in the car remotely, **something that historically could only be done on a workbench or with the engineer in the vehicle.**

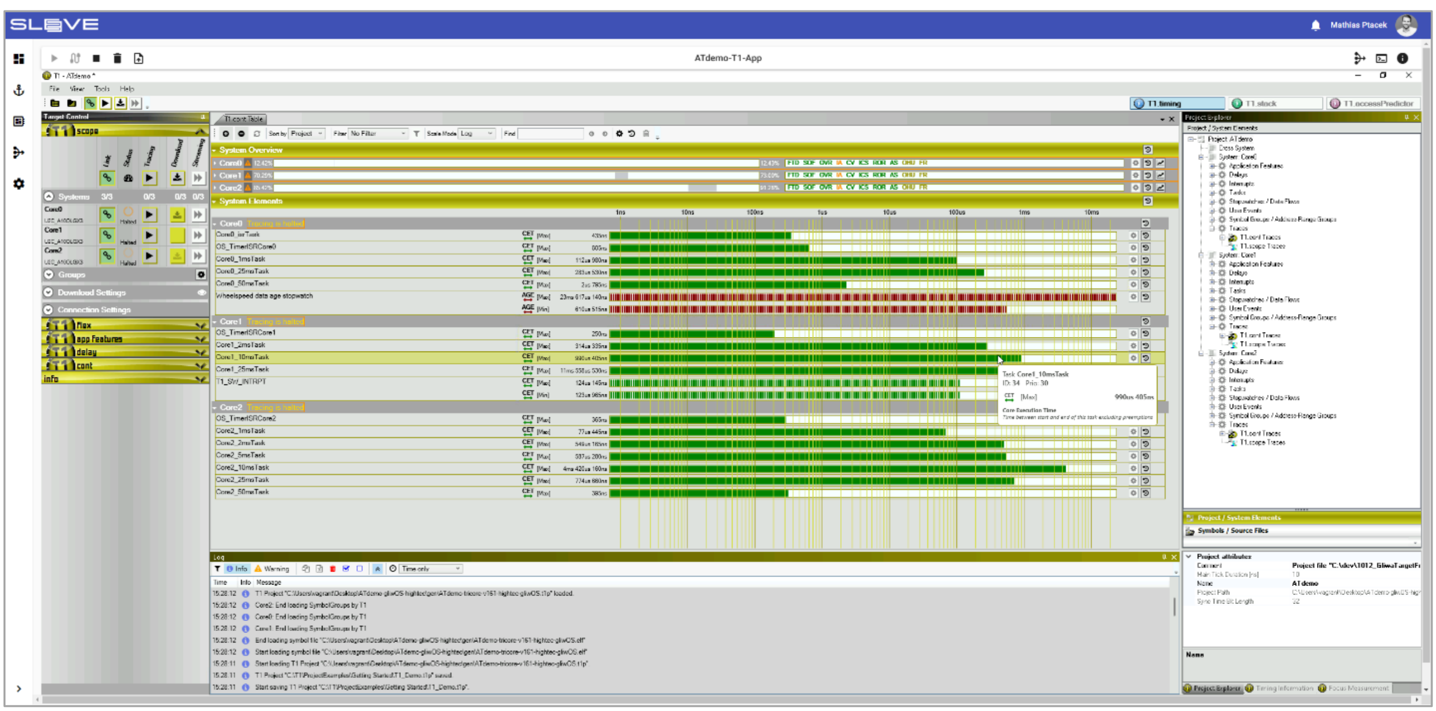

Figure 6 - GLIWA T1 tooling within Sleeve Hub

From a networking perspective, Sleeve's implementation carefully manages bandwidth and latency. Sleeve Hub also compresses and optimizes the remote desktop streaming to ensure interactive tasks (like using a GUI application) remain smooth even on limited bandwidth. On the security side, everything is behind authenticated access. Sleeve Dock has no open ports and connects with an outgoing encrypted tunnel directly to the Sleeve Hub. Sleeve Hub users need to pass multi-factor authentication to gain access to the UI. Data at rest on the Sleeve Dock can be encrypted, and nothing persists in the cloud (the workspaces are ephemeral unless explicitly saved). These implementation details give confidence that remote testing can be done without compromising proprietary data or safety.

In summary, **Sleeve's technical implementation brings cloud computing paradigms (virtual machines, containers, orchestration) directly into test vehicles**. It creates a flexible, programmable layer on top of physical automotive hardware. For Cariad's engineers, this means they can deploy new test capabilities quickly (just by adding a new container or VM template) and can incorporate existing test scripts and in-house applications into a more automated, remotely accessible framework. **The ability to manipulate and monitor every aspect of a test car over the air is a game-changer for productivity.**

CUSTOMER BENEFITS

Implementing Sleeve for remote fleet management has led to significant improvements for both engineers in the trenches and the management overseeing testing programs. This section highlights the key benefits possible and observed, including greater efficiency, reduced maintenance efforts, better team collaboration, and substantial cost savings. These advantages are not just theoretical – they are backed by feedback and data from actual users of Sleeve in an automotive test fleet setting.

Time Efficiency and Increased Uptime: One of the most immediate benefits of Sleeve is the reduction in time wasted on travel and setup. Engineers no longer need to spend half a day driving to a proving ground to update a vehicle, nor wait idle for a specific test car to become available. Routine operations that used to take hours can now be done in minutes remotely. For example, a test engineer at Cariad noted that Sleeve "**saves us 30 min of configuration time for each vehicle per day**", time that was previously spent on connecting equipment and manual adjustments on-site. Multiplied across dozens of vehicles and days, this is a huge boost in productivity. Vehicles also stay operational more often – since vehicles do not have to return to the garage as often for interventions, they can be in testing use for a greater portion of time. Less downtime means more tests can be completed in a given schedule. In practice, this has translated to tighter feedback loops: if a bug is found in morning testing, a developer can remotely deploy a fix by the afternoon, and the same vehicle can be running new tests by evening. Overall, Sleeve enables the test fleet to be used to its full potential each day, squeezing more value out of every test hour.

Reduced Maintenance Effort: From a support and maintenance standpoint, Sleeve dramatically cuts the labor required to keep the fleet devices up-to-date and running. Previously, maintaining a fleet of test devices (updating software, ensuring scripts are the latest version, checking connections) was a constant manual chore. Now, updates can be pushed centrally – tooling updates are promptly delivered to all users and devices across the network via Sleeve's centralized management. This ensures every test car's setup is uniform and current, with far less hands-on tinkering. One tangible example is script maintenance: earlier, if a data logging or update script needed a tweak, an engineer might have had to remote into each device or visit cars one by one to update it. **With Sleeve, the updated script is deployed once to the master template and automatically rolled out to every vehicle's Sleeve Dock**. **Maintenance tasks that used to be "time-intensive to roll out" across the fleet are now largely one-click or automated.** A test fleet manager commented that with Sleeve in place, they spend significantly less effort coordinating logistics and fixes for test devices – those resources can be reallocated to more valuable engineering work instead of babysitting hardware.

Improved Collaboration and Accessibility: Sleeve has become a catalyst for better collaboration among Cariad's engineering teams. Because the platform standardizes the test environments and makes them accessible from anywhere, teams can truly work together on the same vehicle or issue in real-time, regardless of location. **New cases where a developer in Germany and another in the USA jointly debug a problem by sharing the same virtual workspace connected to a car, each viewing logs and swapping control as needed are easily undertaken – something nearly impossible before**. Sleeve effectively provides unified virtual workspaces that the whole team can access, aligning everyone on the same tools and data. This consistency means a bug observed in one place can be analyzed and reproduced by colleagues elsewhere without ambiguity. In addition, onboarding new team members is faster: **instead of setting up a physical test bench for a newcomer, you simply add them to Sleeve and they immediately have access to the fleet and all required software through the cloud**. As one TTTech Auto developer put it, "Sleeve enables us [to do] global remote debugging", allowing experts to contribute regardless of where the car is or where they are. The improved collaboration also extends to external partners or suppliers – with proper security, OEMs like Volkswagen/Cariad can grant a supplier temporary remote access to a specific test vehicle for advanced troubleshooting, rather than having to ship the unit back to the supplier. All these factors lead to a more agile and responsive development process, where the best person for a job can access the test context instantly, instead of being limited by geography.

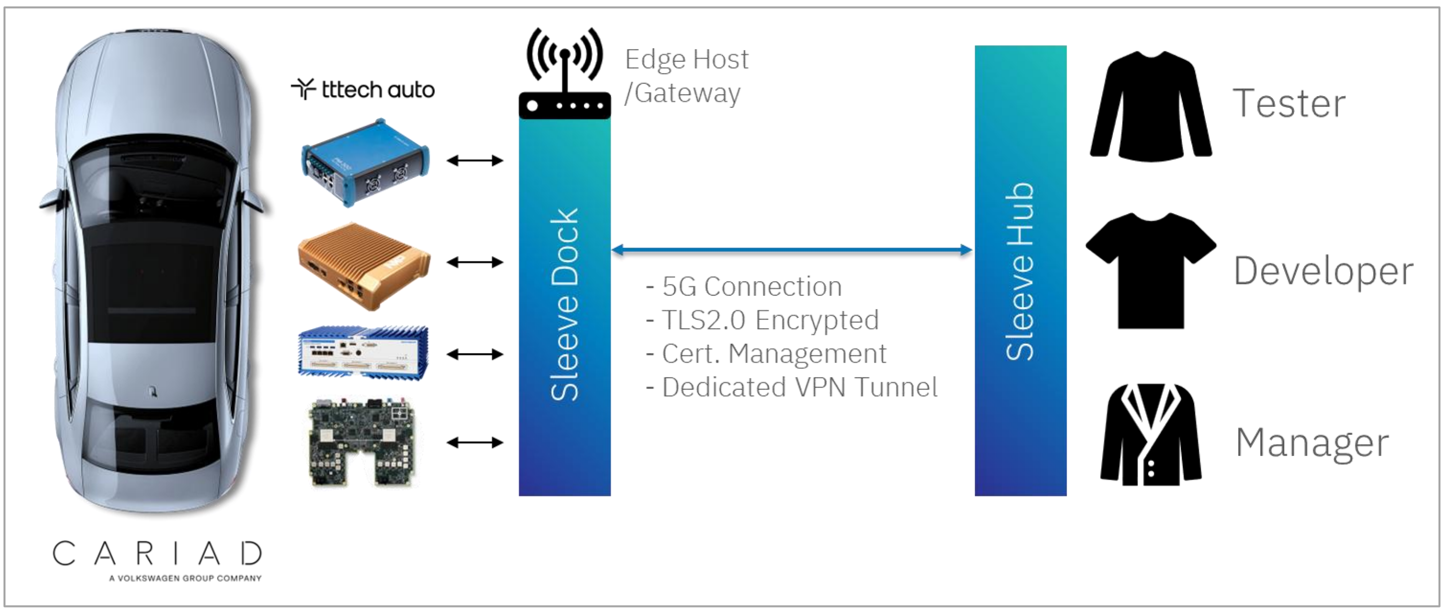

Figure 7 - Sleeve Dock/Hub high-level access

Cost Savings and Resource Optimization: The efficiency gains and reduced labor translate directly into cost savings, which is crucial from an executive management perspective. By minimizing travel and manual processes, Sleeve helps avoid many expenses (fuel, travel hours, shipping equipment, etc.). More importantly, it unlocks better utilization of costly assets. Prototype hardware and software licenses that were often underutilized are now accessible 24/7 by the global team, increasing their effective use and yielding better return on investment. For instance, if only one team could use a specialized data logger due to physical access, that device might sit idle overnight; now teams in different time zones can sequentially use the same equipment via remote sessions, maximizing usage. This also means fewer duplicate purchases of expensive gear – you can potentially manage with less hardware because access is shared more efficiently across the organization. Early metrics show that for certain activities, **Sleeve eliminated around 70% of the manual effort previously required** –

contributing to large operational cost reductions. **To highlight, the analysis projected on the order of €260k+ per year savings for a moderate-sized test fleet (~ 20 vehicles)** thanks to time saved and improved workflows. These cost savings can be scaled to a high number of test vehicles worldwide and easily tap into 2-digit million Euro territory. There are also indirect savings: by catching issues earlier (due to more frequent and thorough testing enabled by Sleeve), costly last-minute fixes or project delays can be avoided. In summary, Sleeve not only accelerates engineering work, it does so in a way that uses human and hardware resources much more effectively, which is reflected in the bottom line.

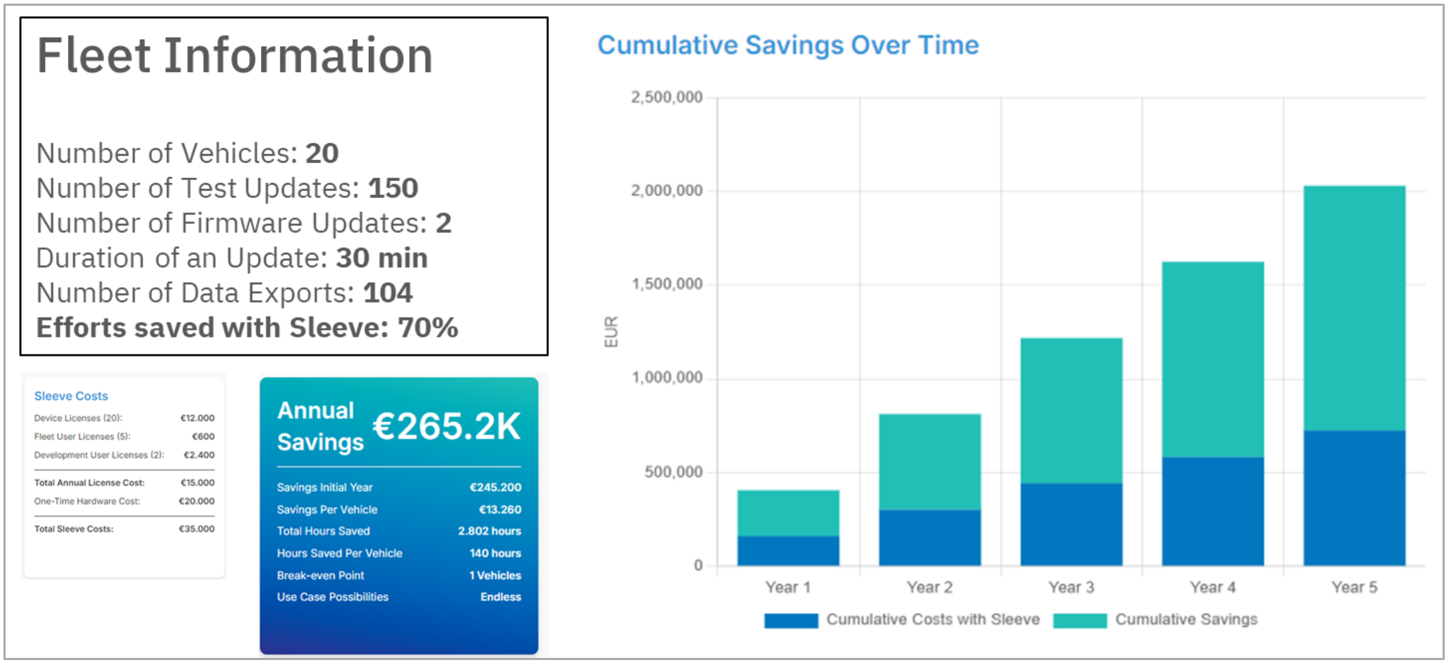

Figure 8 - Cost savings with Sleeve

All these benefits contribute to a compelling value proposition. Engineers get a more convenient and powerful way of working, and management sees faster project progress and lower costs. Cariad's leadership has recognized that a platform like **Sleeve aligns with the strategic goal of digitalizing the development process and enabling the software-defined vehicle**. By turning physical testing infrastructure into a cloud-managed resource, Sleeve fits into broader initiatives of increasing automation and data-driven development. The next section will provide a case study with concrete numbers and outcomes from deploying Sleeve in a test fleet, solidifying the impact it has had.

An interactive savings calculation is available via https://sleeve.dev/fms-savings-calculation/

CASE STUDY AND METRICS

To illustrate the real-world impact of Sleeve, consider its deployment in one of Cariad's test fleets used for developing advanced driver assistance systems. This fleet consists of about twenty prototype vehicles distributed across different test locations. Each vehicle was originally outfitted with a data logging solution centered on a consumer-grade Windows tablet PC connected to a TTTech Auto data logger and various test interfaces. The role of that tablet was to run in-house software and some custom scripts during test drives and garage stays. However, the original state had numerous limitations: the tablets were not built for automotive conditions (often overheating or shutting down in the field) and updating software on them required hooking each one up to a keyboard or network individually. On top of that, if a script crashed or a tablet froze, the data upload might stop collecting data and nobody would know until the car returned from the test. Scaling this setup to more vehicles or use cases was difficult, and a lot of engineering time went into simply keeping the logging systems running and retrieving the data manually.

With Sleeve, Cariad overhauled this setup. In each car, the fragile tablet can be replaced with a rugged embedded host unit running Sleeve Dock. Right away, this solved the hardware reliability issues: the Sleeve Dock hosts are automotive-grade computers with ample processing power and designed cooling, so they handled continuous operation in the vehicle without incident (no more overheating or dying batteries). The integrated connectivity with 5G and dual SIM is on par with cutting-edge industry routers and improves remote accessibility – testers could consistently reach the in-car system from anywhere, even when the car was out on public roads or in a garage. All the logging software and custom scripts that ran on the old tablets were containerized or put into a Windows VM managed by Sleeve. Deployment was done in a systematic way: a master container image with the TTTech logging configuration software and Cariad's data upload scripts was prepared and then rolled out to the Sleeve Dock(s). This meant every car now is able to have an identical logging environment, whereas previously each tablet might have drifted to slightly different versions. Script updates that used to take high effort to coordinate (and could be "forgotten" on some vehicles) became instant – **one update to the container image, and Sleeve Hub propagates it fleet-wide**. The Sleeve Dock's autostart and remote management also ensured that the logging system in each car would start up automatically with the vehicle and be reachable at any time. Nothing needs to be manually launched by the test driver.

Crucially, the workflow for engineers interacting with these test vehicles changes for the better. Now, when a test run is completed, engineers do not have to physically retrieve the data logger or its storage. They simply log into the Sleeve Hub portal, open a remote workspace for that vehicle's Sleeve Dock, and pull or upload the data logs and triggered recordings over the air. In fact, most data uploading is automated – as soon as the car connects and is idle, a Cariad script in the Sleeve Dock managed VM automatically pushes the latest log files to a cloud server at Cariad. What used to perhaps require someone to "return to the garage" with the vehicle and plug in a hard drive now happens without human intervention. One test manager highlighted that vehicles now "do not have to return to the garage that often" because virtually every action (besides physical repair) can be done remotely on the road. Even configuration changes – say the testing team wants to tweak the logger to record higher-fidelity data for a certain sensor – can be done on the fly via Sleeve, rather than waiting until the car is back in the workshop. **This keeps the cars out in the field longer and increases the number of test miles driven per week, since downtime for configuration or firmware updates drops dramatically**.

The benefits of this "after Sleeve" state are reflected in concrete metrics estimated jointly with the customer. For a 20-vehicle fleet, we estimated the time spent on configuration and data handling tasks before and after Sleeve. The results were striking: they found roughly a 70% reduction in manual effort for those tasks when using Sleeve. On average, each test vehicle saves about 30 minutes per day of engineer time (as mentioned, much of it was previously spent on hooking up equipment, configuring or downloading data) – which across 20 vehicles and a typical testing schedule accumulates to significant hours saved. In fact, internal calculations showed about 2,800 hours saved per year for the fleet as a direct result of Sleeve implementation. Put in financial terms, assuming a blended engineering labor rate, this equated to approximately **€265,000 in annual savings for that fleet**. These numbers exclude the cost from travel reductions– for example, the team virtually eliminated the need for trips to vehicles for data retrieval. The cost of deploying Sleeve (the hardware units and software platform) was easily justified by these savings, **paying back in well under a year.**

Beyond labor and time, Cariad also looked at the effect on vehicle utilization. With Sleeve, each vehicle's availability for testing (as opposed to being parked for service or waiting for an engineer) improved markedly. With an estimated 15% more active testing time per vehicle on average, configuration changes no longer steal chunks of the day. Over the course of a development project, this translates to potentially more test scenarios completed and additional validation coverage – which can be invaluable for quality and safety outcomes. There’s also a cascading effect: quicker turnaround on testing allows earlier discovery of issues, which in turn gives engineering teams more time to fix them before deadlines. For example, a critical issue in an ADAS algorithm is found in a test drive; **using Sleeve, developers can then remotely debug and pull gigabytes of log data immediately and diagnose the problem overnight, issuing a software patch by the next morning.** The same car can then receive the update via Sleeve that day and go back out testing the fix, avoiding what could have been a delay of several days waiting for data and deploying a technician. **Such rapid iteration was previously unattainable.**

In summary, this case study of deploying Sleeve in a test fleet demonstrates a clear ROI (Return on Investment). The technical improvements translated directly into measurable time and cost savings, while also improving test throughput and collaboration. Engineering teams are able to report higher satisfaction because they could focus on actual testing and debugging rather than on logistics. Management will appreciate that critical testing was completed on schedule (or ahead of it) and with less surprise costs.

Sleeve effectively turned what was once a labour-intensive process into a streamlined, software-defined operation. It validated the premise that investing in better remote tooling for test fleets yields strong returns in the automotive domain.

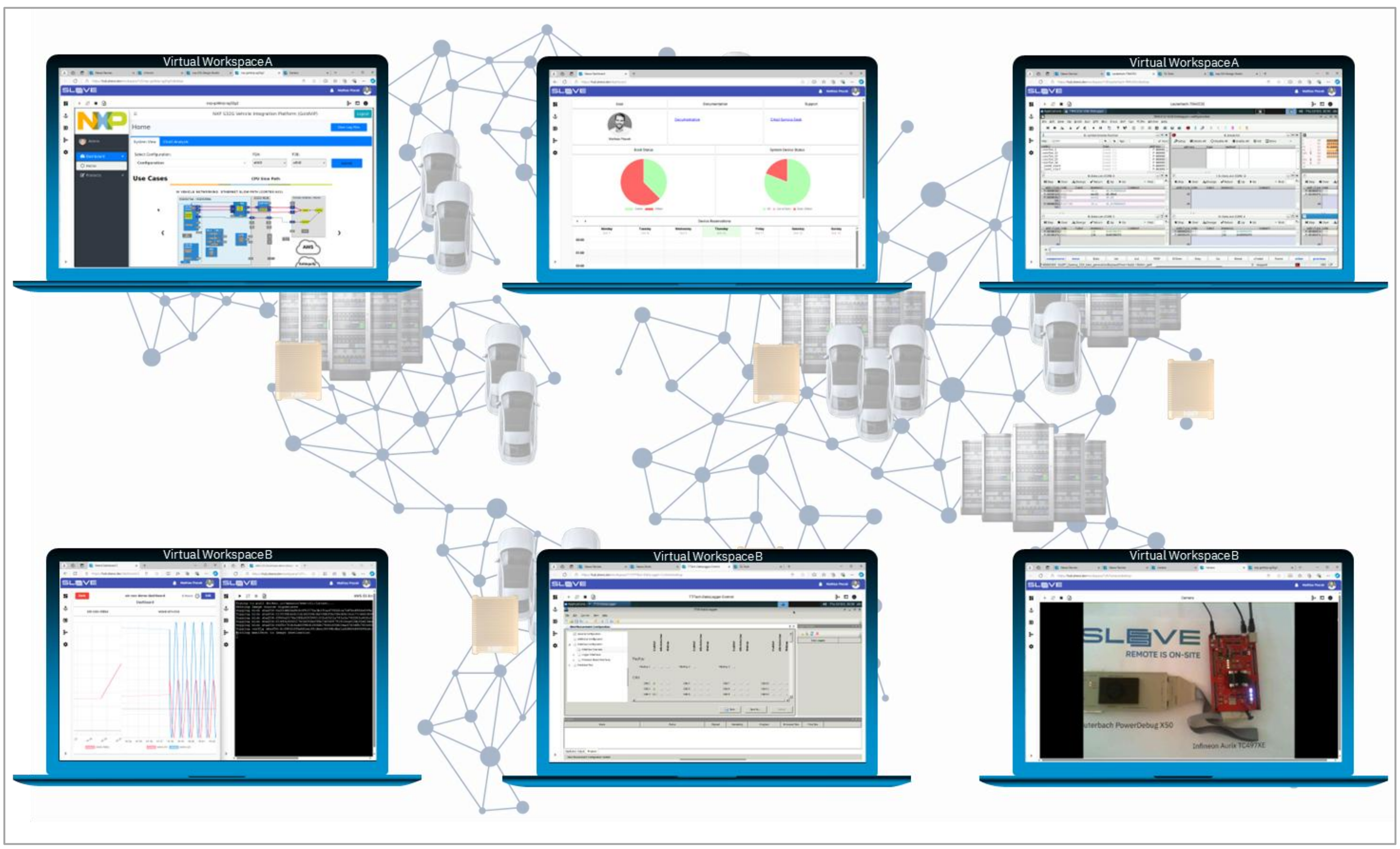

Figure 9 - Access your Sleeve Hub from anywhere

CONCLUSION

The adoption of Sleeve for remote fleet device management has proven to be a transformative step for Cariad's automotive testing operations. This whitepaper has detailed how Sleeve directly tackles the entrenched challenges of managing distributed test vehicles – from difficult remote access and slow update cycles to collaboration hurdles and underutilization of resources. By deploying an edge-cloud solution that brings the lab to the vehicle, Cariad's engineers are now able to work without physical constraints, accelerating the pace of development while reducing effort and cost.

Key Advantages can be summed up as follows**: Sleeve provides instant, browser-based access to any device in any test car, effectively eliminating distance as a factor in hardware-in-the-loop testing. It ensures consistency and control through virtualization and centralized management** – every user sees the same environment and software versions, and updates propagate to all corners of the fleet effortlessly. **It improves fleet uptime and data flow**, as vehicles spend more time collecting data and less time waiting for someone to plug in a cable. **It fosters true global collaboration, enabling teams spread across continents to jointly interact with the same test setup in real time.** And importantly, **all of this is achieved with a strong emphasis on security and reliability**, which are non-negotiable in the automotive industry (secure VPN tunnels, authenticated access, and robust hardware mean the solution is enterprise-grade in its trustworthiness).

From a business perspective, Sleeve demonstrates how embracing digital transformation in vehicle testing can yield tangible ROI. **The efficiency gains translate to faster validation cycles and potentially quicker time-to-market for new features** – a critical competitive edge in the race for software-defined vehicles. The cost savings free up budget that can be reinvested into further R&D or into scaling up test coverage. Moreover, by reducing the need for travel and shipping, Sleeve contributes to safer operations (less driving back-and-forth with prototype cars) and even to sustainability goals (fewer logistics-related emissions). It's a compelling example of how a smart infrastructure investment pays dividends across multiple dimensions.

Looking forward, the success of Sleeve in the prototyping and testing phase opens doors to future applications in fleet management and beyond as Sleeve is partnering with test and device tooling vendors like TTTech Auto and Gliwa. One can envision extending similar remote management capabilities to other fleets – for instance, a fleet of vehicles in a pilot program with customers could be monitored and updated using a Sleeve-like approach, ensuring issues are caught and fixed remotely. **As vehicles in the field become more software-driven, tools like Sleeve might assist not just in development but in after-sales diagnostics or updates, essentially enabling a Blackbox recording approach for highly safety-critical autonomous taxi fleets**. In testing specifically, the data and remote control infrastructure that Sleeve provides could integrate with emerging trends like digital twins and hardware-in-the-loop simulation. Engineers could remotely swap a physical ECU in a car with a simulated ECU in a Sleeve workspace for certain tests, blending physical and virtual testing seamlessly. The platform's ability to handle containers and VMs at the edge hints at even more flexibility – perhaps **running on-vehicle machine learning models or real-time analytics during tests to filter data**. As Cariad explores autonomous driving and connected car services, **having an established remote management capability for test assets will prove invaluable for scaling those complex testing scenarios along cross-functional and cross-company teams worldwide.**

In conclusion, Sleeve has enabled Cariad to turn a corner in how it manages and utilizes its test fleets. It exemplifies the shift toward a more agile, software-centric approach in automotive development, where physical limitations are minimized by clever use of technology. By balancing technical detail with clear business value, we have seen that **Sleeve not only solves today's pain points but also lays the groundwork for tomorrow's innovations in fleet management and vehicle testing.** It's a solution that empowers engineers to do their best work from anywhere, and empowers management with a more efficient, cost-effective operation.

As the automotive industry continues to evolve rapidly, tools like Sleeve will be key in keeping development and testing processes just as cutting-edge as the vehicles themselves, driving forward the next generation of mobility.

ABOUT & CONTACT

Sleeve

Sleeve offers a cutting-edge Platform-as-a-Service solution for global access to distributed infrastructure. It empowers users with seamless virtualization of workspaces directly within their web browsers, facilitating interaction with remote devices, digital twins, tools and remote data – all within one unified platform.

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CARIAD

CARIAD SE is a Volkswagen Group subsidiary specializing in automotive software development. It focuses on creating unified digital platforms, autonomous driving technologies, and innovative software solutions. Its goal is to transform Volkswagen's vehicles into intelligent, connected mobility ecosystems.

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TTTech Auto

TTTech Auto is an Austrian unicorn technology company and a leading system solution provider for the software-defined vehicle, specifically for safety-critical applications and automotive data loggers.

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GLIWA

GLIWA is one of the world's leading vendors of analysis tools for embedded software. T1 provides first class analysis for developing, visualizing, optimizing and verifying embedded software.

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