BOSCH

Re-Routing to Safer and More Intuitive Vehicles with AI-Powered Verification and Validation

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Executive Summary

Thriving in the evolving automobile landscape demands the creation of vehicles that make the grade. Running time-consuming, manually-intensive, and expensive automotive simulations that mimic the physical environment manually does not guarantee precise results that match real-world scenarios. To ensure remarkable performance of automotive software with zero bugs, quicker iterations, and robust testing, product engineers must leverage AI-based self-learning models.

Today, 47% of automotive AI use cases

in manufacturing are categorized for quality control. Given the shift to autonomous driving, software-defined vehicles (SDVs), and customer- centricity, there is a pressing need to create safe and reliable vehicles. From identifying and addressing design errors prior to physical prototypes to streamlining the designs, minimizing the ecological impact, and enhancing advanced driver assistance systems (ADAS), AI acts as the dynamic catalyst in the V&V space.

Bosch SDS is reshaping the V&V process — enabling organizations to build intelligent automobiles while embracing sustainable processes and connected systems — driving companies toward #SmarterDigital.

Navigating the Transforming Automotive Landscape

Technological advancements, changing customer needs, and newer sustainable policies have pushed for digitization across industries – automotive being no exception.

a. The Emergence of Software-Defined Vehicles

Customers now anticipate connectivity, personalization, and automation more than hardware specifications. This requires original equipment manufacturers (OEMs) to prioritize the software counterpart as much as traditionally desired hardware aspects in building SDVs. As a result, cars are no longer transportation vessels — they are now defined by innovative HMI features and superior cabin experiences. The SDV market is expected to be valued at more than USD 650 billion by the end of this decade, creating three times more OEM revenue between 2023 and 2030.

b. ADAS Proliferation

According to a study, 51% of car buyers expect to switch to a fully autonomous car in the upcoming years. However, at the moment, only 25 to 30% of consumers have basic ADAS features, which they rarely use due to safety concerns and fear of technology failure. OEMs are leveraging predictive maintenance to strengthen the ADAS system with night-time pedestrian detection systems, alerting drivers about road conditions, upcoming hazards, and lane departure warnings.

c. Development of Autonomous Driving

Autonomous driving is modernizing consumers' driving experience, providing increased safety, convenience, and delight. With autonomous driving in place, employees can work while commuting, thereby shortening the workday. Additionally, it can reduce the need for roadside assistance and repairs by limiting the number of accidents. This advancement is projected to generate between USD 300 billion and USD 400 billion by 2035 in the passenger car market.

d. Increased Connectivity

Connected cars exchange information and integrate data from external networks such as the electric vehicle grid, surrounding vehicles, and public infrastructure to enable bidirectional communication. They share internet access and send vehicle health reports and remote diagnostics to minimize delays, enhance the driving experience, and prevent car breakdowns. About 40 to 60% of survey participants suggested that they would purchase a car for individual connectivity features.

From advanced vehicle environmental perception to connected driving experiences and enhanced safety, customer needs are clear and necessitate AI-led robust verification and validation of new processes and tools.

Reshaping V&V with AI

The adoption of AI in every modern system has been rising significantly. If AI elements experience failure, it can lead to the collapse of the entire system, necessitating the incorporation of AI in V&V. AI models' functions in the automotive industry go beyond task automation. They span the entire value chain – from requirements gathering to reporting test results – providing a continuous feedback mechanism on safety-critical systems. Moreover, AI models intelligently construct optimized test suites that identify potential problems far more effectively than manual approaches. This is achieved by evaluating vast databases of software requirements, previous issues, sensor data, and code modifications.

By driving realistic simulations with a wide range of weather patterns, elaborate road designs, varied light intensity, and complex traffic patterns, AI guarantees reduced time-to-market, zero recalls, cost savings, and enhanced safety.

Tap into Critical AI-Based Use Case Opportunities

The demand for affordable, high-quality, and novel vehicles is increasing production lifecycles, testing costs, and time-to-market while reducing return on investment (ROI) and market share. Bosch SDS brings its decades-long expertise in advanced V&V solutions, assisting clients in achieving true success with AI. Let's take a look at some of the most critical and accessible use cases within this space:

I. Vision Test Data Augmentation

Vision Test Data Augmentation (VISTA) leverages computer vision (CV) to verify and validate ADAS and autonomous vehicles in different scenarios, ensuring the safety and reliability of cars across different environments.

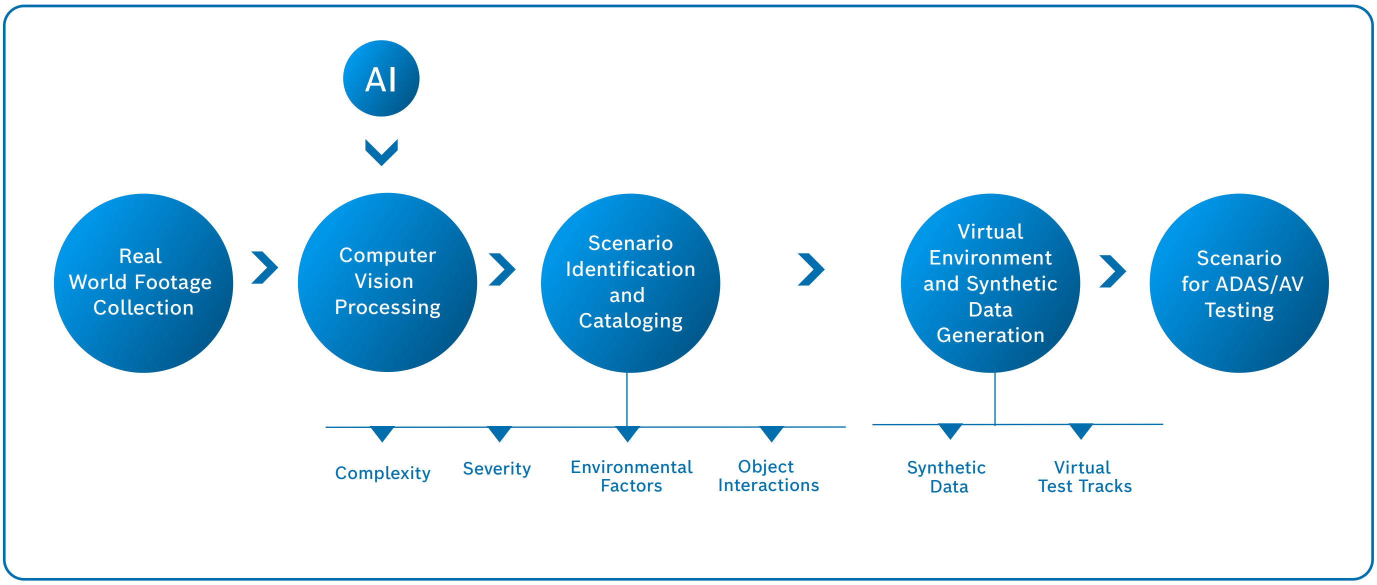

Figure 01: A high-level workflow of VISTA

Most scenario-generation tools focus on processing sensor data from a single test drive. However, VISTA collects and analyzes extensive footage through cameras mounted on vehicles for broader scenario creation. VISTA not only reconstructs the ego vehicle's path but also identifies and categorizes different objects and events within the scenarios.

Figure 02: Multiple image outputs from a single input

Furthermore, the VISTA library helps create multiple use cases with a single input for validating different environmental factors. This is done by applying transformations to the input and verifying if the transformation maintains the expected relationship between the input and the output.

Weather	Snowing	Reduced Visibility, White ground and air
	Raining	Reduced Visibility, Sensor Wet
	Sunny	High brightness, glare, reflection, shadows cast
	Cloudy	Less light depending on the cloud level
	Foggy	Reduced Visibility
	Night/Day	Different light level, partial visibility (where there is light)
Environment	Construction	Change from recorded map / expected environment
	Traffic Signs	Need to be captured to define rules of the road, may change over time
	Road Marking	Defining lanes etc. different levels of wear
	Connecting Roads	Can we turn? Is someone coming? Need to give way
	Parking Lots	Looking for parking spots, Is someone coming?
	Holes in the road	Road's wear and tear overtime
	Debris on road	People/Storms anything on the road, you don't want to hit them
	Strange markings	Was it a Vandal, a construction crew, an accident
	Animals Corssing	Is it a cat? A god? A fox? A chicken? Who crossed the road?
	Puddles	After rain, your road may be covered in reflecting pools, possibly deep
	Snow	During winter, much of the road can be covered and hard to see
Vehicle/Sensors	Car Position	Where is the car itself in relation to road/traffic?
	Car Rotation	Is the car (and thus sensor) straight or partially rotated (e.g, tire on curb)
	Sensor Type	Lidar? Camera? What type of camera or another sensor?
	Sensor Quality	Is the image (or sensor reading) high/low resolution? Other attributes?
	Sensor Position	What part of the car is the sensor at? What is the camera angle?
People	Pedestrians	Sometimes (and in some countries) people might walk
	Cyclist	Often on the road, hand signals for turning, may fall
	Wheelchairs	Not the fastest moving/reacting vehicle if crossing the road
	Buggies	Someone walking with their babies in a stroller, side of the road
	Crawlers	Maybe they had too much to drink or have not learned to walk yet

Figure 03: Possible use cases and scenarios

II. GenAI in CAPL Scripting

By employing CAPL, a scripting language for automobile network testing and GenAI, areas like code generation and assistance, documentation and understanding of complex code, and test scenario suggestions are made more seamless. The combination of GenAI and CAPL boost testing efficiency, enhances the accuracy and reliability of CAPL scripts, and saves costs.

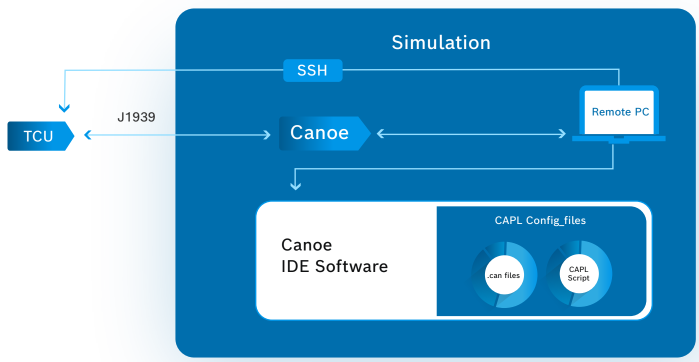

Figure 04: Workings of conventional CAPL

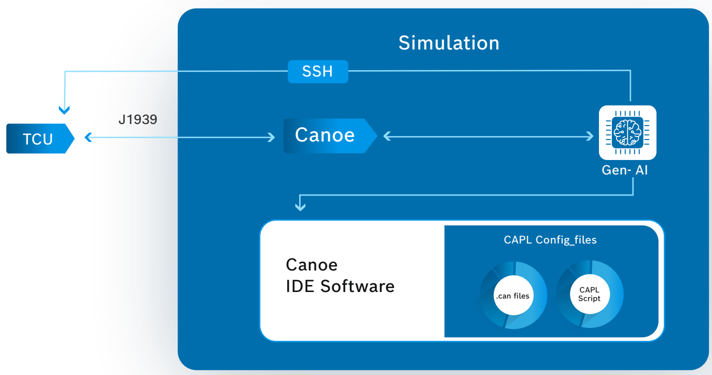

Figure 05: Workings of CAPL with GenAI

III. Self-Healing Test Automation Framework

The self-healing test automation system spontaneously detects and rectifies issues in UI by recognizing patterns in DOM states. Data collected from test automation runs is used to train ML models utilizing the LCS algorithm, which generates new test cases based on identified subsequences. This is coupled with ongoing testing and debugging, enabling us to continuously enhance test coverage and mitigate the risks of test failures. This process minimizes the time and effort required for manual testing, increases test coverage, and boosts the effectiveness of software testing.

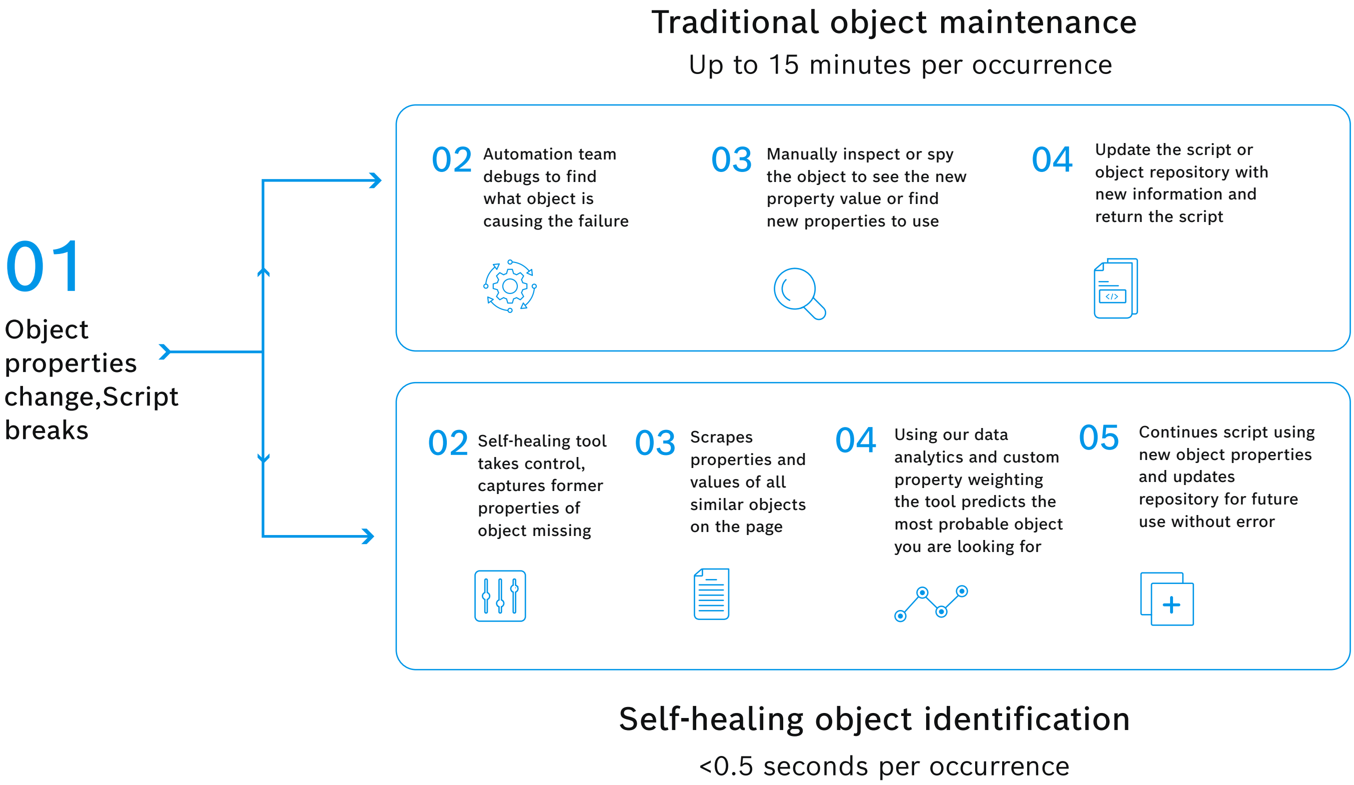

Figure 06: Traditional object maintenance vs self-healing identification

IV. AI in Model-Based Designing

The model-based design (MBD) is utilized in the product development cycle to design, implement, and analyze complex systems. However, creating high-fidelity MBD models for simulation is a time-consuming process. Leveraging AI in this long process significantly reduces overall model cycle time. This is done by collecting data, training AI models, and importing trained AI models into a system design platform, such as *Simulink®, for system-level simulation and testing.

**Simulink®, a product of MathWorks, is a MATLAB-based platform that specializes in building simulation models, conducting continuous testing and verification of embedded systems, and performing fault analysis and predictive maintenance, among other capabilities, prior to hardware development.*

With Bosch SDS's unique AI-led approach, we witnessed a **75-82%** reduction in timelines for moderately complex models.

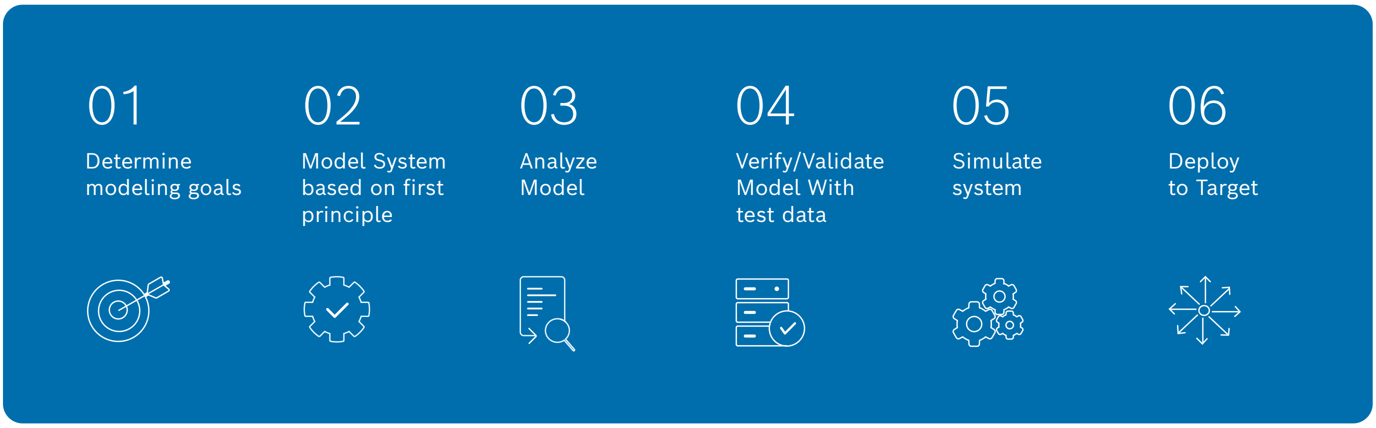

Figure 07: Traditional approach to MBD

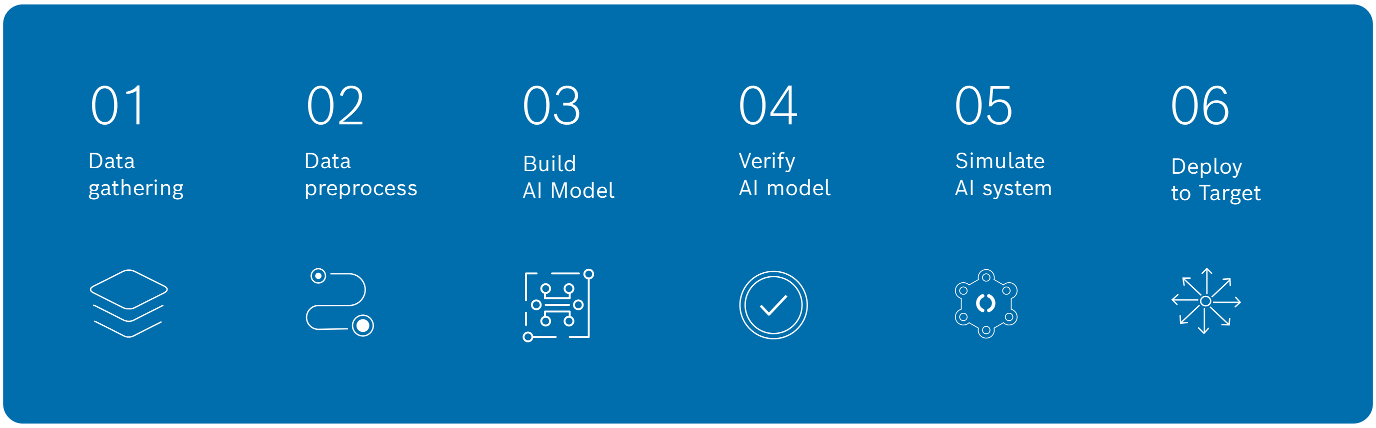

Figure 08: AI-based approach to MBD

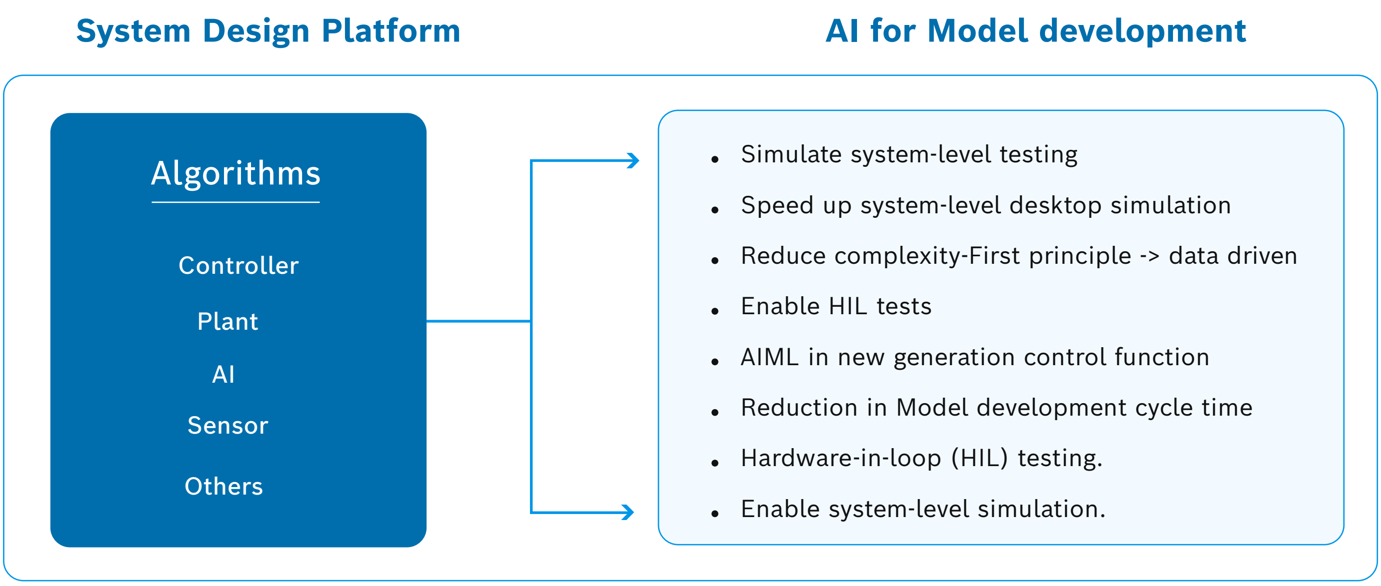

Figure 09: System design platform

Complexities to Consider with AI-Driven V&V

For AI-driven systems to ensure vehicles are in optimal condition before they hit the road, establishing core tenets such as the ethical use, reliability, and safety of AI is crucial. Here, AI-led V&V becomes key to developing vehicles that meet all the necessary regulatory parameters of autonomous vehicles.

However, implementing AI-driven V&V technology comes with its own set of complexities that need to be considered:

- Before AI can validate autonomous vehicles, AI systems must undergo rigorous testing in numerous scenarios to ensure they can enhance the safety of modern vehicles rather than develop risky driving systems.

- When it comes to AI-powered testing, understanding why AI made specific decisions is now fundamental. While building an AI system that is transparent, bias-free, and produces trustworthy decisions, maintaining a balance between performance and explainability is equally paramount. Trading off one for the other might render AI systems less interpretable.

- Finally, data privacy and security are of great concern, given the extensive data required on driver behavior and vehicles for training AI models. To ensure resilient cybersecurity measures, developers must obtain user consent and employ robust anonymization techniques.

Bosch SDS understands there are complexities; with our proven cross-domain expertise, deep engineering capabilities, and advanced digital labs, we can help you smartly navigate any potential roadblock. Our measures include but are not limited to implementing rigorous validation protocols designed for AI in safety-critical applications, as well as a commitment to transparency and explainability within AI models. This further enables us to confidently leverage AI's transformational potential within the V&V landscape.

Speed Ahead with Bosch SDS

With AI disrupting the V&V lifecycle through AI-powered test case generation, hyper-realistic simulations, and analysis of vast datasets for failure patterns, we are moving towards safer and more reliable driving experiences. The future of mobility is all set to be driven by cutting-edge HMI and advanced software for autonomous vehicles.

Bosch SDS is leading the charge with state-of-the-art technologies like VISTA, AI-enabled script generation, self-healing automation framework, and AI in MBD. By harnessing cutting-edge tools and more, we can assist businesses in simplifying testing, reducing the possibility of human errors, and generating insights that enhance connectivity, boost efficiency, and, ultimately, advance the smarter vehicles of tomorrow.

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Established in 1886, the Bosch Group is a leading global partner for technology and services. Bosch Software and Digital Solutions (Bosch SDS) is a global digitalization provider of consulting, engineering, and IT services. We help enterprises Switch to Smarter Digital, a forward-looking approach to digitalization that is centered on the user. From creating new digital business models, enabling resilient future-proof enterprises and accelerating sustainability goals, Bosch is a trusted partner for a multitude of industries across the world.

As a global technology partner, Bosch SDS operates in North America, Europe, the UK, the Middle East, and Asia Pacific markets through a network of on-shore, near-shore and off-shore delivery centers.