Journal of Traffic and Transportation Engineering 13 (2025) 1-16
doi: 10.17265/2328-2142/2025.01.001

Intelligent Operations: Global Public High-Power Charging Networks

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Abstract: The global public HPC (high-power charging) network for EVs (electric vehicles) is rapidly expanding. This growth is crucial for supporting the increasing adoption of EVs but highlights the industry's early stage. Regional maturity varies, with China leading due to strong government support, followed by Europe and the United States. A significant challenge is the lack of industry standards, causing inconsistencies in charger types and payment systems. Efforts are underway, to ensure interoperability and reliability. Interoperability is crucial for the success of EV HPC infrastructure, ensuring seamless integration among charge points, management systems, and service providers. Despite the use of protocols like the OCPP (Open Charge Point Protocol), variations in implementation create complexities. Ensuring uniform standards across the ecosystem is essential for reliability and efficiency. Vendor-specific error codes, which are more detailed than standardized codes, are vital for diagnosing issues but lack standardization, adding complexity. Addressing these challenges is key to supporting widespread EV adoption and enhancing user experience. To provide a compelling driver value proposition, EV charging services must be reliable and seamless. The operations and maintenance of the HPC network must be cost-effective and leverage the intelligence of the integrated ecosystem. The technical complexity of managing high-power DC charging, combined with diverse authentication and payment systems, results in numerous potential issues. Moving from reactive to predictive maintenance is essential for undisrupted operations and a smooth driver experience. Shell's Intelligent Operations Technology Strategy incorporates GenAI elements in its advanced analytics and operational performance management tools. By ingesting big data from multiple sources across the EV ecosystem, Shell engineers can perform detailed pattern recognition and targeted troubleshooting. Monitoring, configurable alerting, and remote fixing based on auto-healing and targeted auto-allocation enhance charger availability and reduce downtime. This automation has evolved Shell's maintenance and operations strategy from reactive to predictive, improving overall charger performance and user satisfaction. Key achievements include transitioning to prescriptive and preventive asset management approaches, significantly improving uptime and charging experience, and increasing commercial value through cost reduction and enhanced revenue. Future challenges include evolving OCPP, integrating data from non-OCPP systems, and ensuring interoperability across diverse systems. Standardization and cross-collaboration within the industry are essential for smooth interoperability, higher uptime, and increased CSR (charging success rate). Technological innovations will further shape the industry, promoting stabilization and efficiency as it matures.

Key words: e-Mobility, charging ecosystem, intelligent operations, predictive maintenance, GenAI.

1. Introduction and Status Quo of the Public HPC (High-Power Charging)

The global public charging network for EVs (electric vehicles) is in a dynamic and rapidly evolving state. As an emerging industry, it faces several challenges and opportunities that vary significantly across different regions.

The public charging infrastructure is still in its infancy, characterized by rapid growth and continuous technological advancements. As of the end of 2022, there were approximately 2.7 million public charging points worldwide, with a significant portion installed in the past year. This rapid expansion is crucial to support the increasing adoption of EVs, but it also highlights the industry's nascent stage.

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The maturity of public charging networks varies widely across regions. For instance, China leads the world with the highest number of public chargers, both slow and fast, driven by strong government support and high urban density [1]. Europe follows, with countries like the Netherlands, Great Britain, Germany, and France making significant strides in expanding their networks to Scandinavia and Switzerland. In contrast, the United States has seen slower growth, although recent federal initiatives aim to accelerate the deployment of chargers [1].

One of the major challenges facing the global public charging network is the lack of industry standards and regulatory frameworks. This absence leads to inconsistencies in charger types, payment systems, and accessibility, creating a fragmented user experience. Efforts are underway in regions like the European Union to establish regulations that ensure interoperability and reliability of charging infrastructure.

The market for public charging infrastructure is highly competitive, with numerous players, ranging from established energy companies to startups. This competitive landscape is typical of an immature industry, where some companies thrive while others struggle to survive. The rapid pace of technological innovation means that many companies are still debugging and refining their solutions to meet the growing demand and evolving standards [2].

2. Challenges of the Public HPC Network

One of the major challenges facing the global public charging network is the lack of industry standards and regulatory frameworks. This absence leads to inconsistencies in charger types, payment systems, and accessibility, creating a fragmented user experience. Efforts are underway in regions like the European Union to establish regulations that ensure interoperability and reliability of charging infrastructure.

Operating global public HPC networks introduces additional complexities. These include challenges in data visibility and interpretation, KPI (key performance indicator) consistency, issue diagnostics and handling, and integration with digital products and services beyond EV charging. To address these, there is a growing emphasis on global network performance transparency and KPIs to monitor the reliability and perceived driver experience of HPC infrastructure. The massive ramp-up plans for charging infrastructure globally necessitate a multi-system approach, involving multiple hardware systems, CPMSs (charge point management systems), and digital technology providers. Achieving engineering and operational excellence in this complex environment requires interoperability and observability from an end-to-end perspective. This includes the need for a data standard that enables “plug & play” integration of new ecosystem elements and the implementation of best practices in technology operations at scale. As the industry matures, there is an increasing focus on cost and profitability, presenting opportunities for automation and leveraging AI to transition to an intelligent operations model rather than a reactive and manual approach.

For example, a major player like Shell, which operates HPC networks globally, faces numerous challenges. These include managing a high volume of error codes daily, handling significant helpdesk call volumes, and processing millions of technician tickets annually (> 1 million). Shell also manages over 10 different charge post manufacturers and a similar number of front and backend systems, alongside a diverse range of grid providers and mobile network operators.

There are three major challenges: the complexity of the ecosystem, end-to-end interoperability from an operations excellence perspective, and the data quality and data consistency of vendor error codes.

2.1 Complexity of the Ecosystem

The public charging ecosystem is shaped by many stakeholders operating different hardware and IT (information technology) systems for charging infrastructure operations and billing, all with access to different charging data sources (Fig. 1).

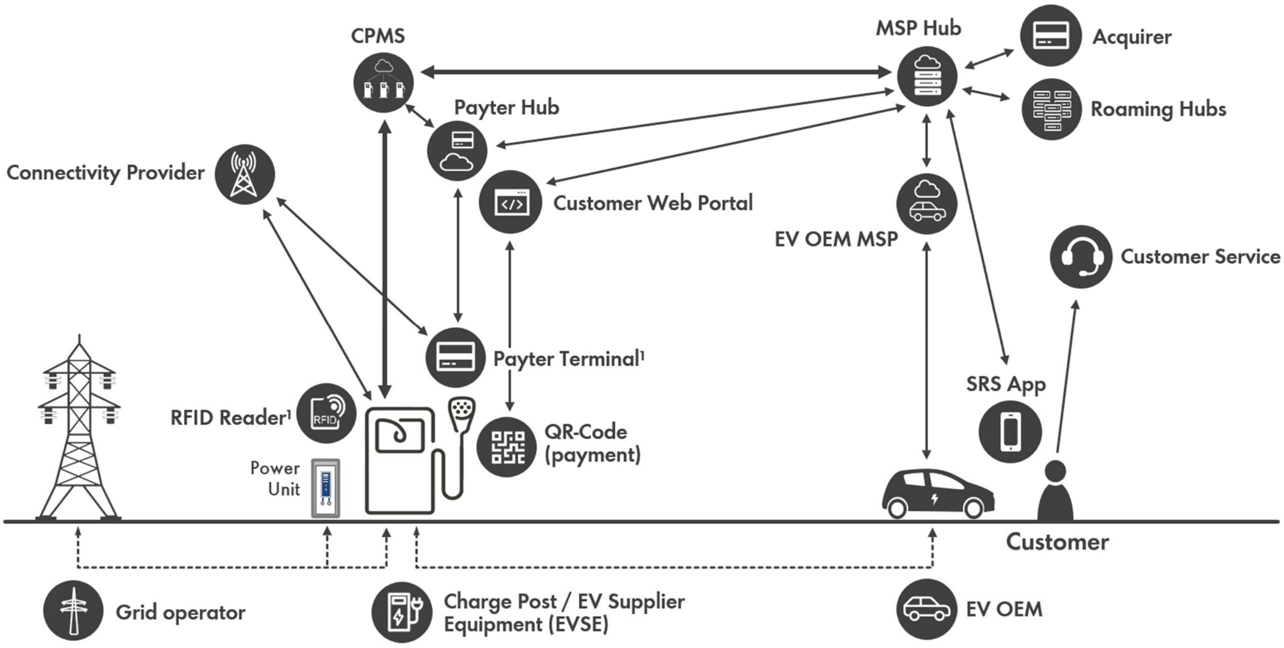

Fig. 1 Example overview of a public charging ecosystem (© Shell plc.).

The core of a public charging ecosystem is the charge post, also called the EVSE (electrical vehicle supplier equipment), including its payment terminal and features (if any), the CPO's (charge point operator) CPMS, as well as the MSP's (mobility service provider) solutions. Other parties to the EV charging ecosystem are the grid operator, the connectivity provider, the backend system provider, the acquirer, roaming hubs, technical or driver service interfacing systems and services, and the EV, including its driver.

2.1.1 A Short Introduction to the Three Core Ecosystem Elements

• An MSP is a company or, in this context, a solution that offers services to EV drivers, such as access to a network of charging stations through a web or mobile app. These services typically include finding available charging points, managing payments for charging sessions, and additional features like rewards programmes or EV roaming [3, 4].

• A CPMS is a crucial operating system for managing EV chargers. It provides centralized control over various aspects of EV charging stations, enabling operators to start or stop charging sessions, accept payments, and send invoices. Additionally, a CPMS offers real-time monitoring and diagnostics, ensuring the efficient operation and maintenance of the charging infrastructure. By integrating with other digital services and platforms, a CPMS enhances the overall user experience and supports the scalability of EV charging networks [5].

• An HPC is an advanced charging station designed to deliver rapid charging for EVs. Key features of HPCs include:

- high output power: capable of delivering up to 350 kW, significantly reducing charging time.
- wide voltage range: supporting a range from 150 to 920 V DC (direct current), accommodating both current and next-generation EVs.
- dynamic power sharing: allowing simultaneous charging of multiple vehicles by distributing power efficiently.
- integrated cooling system: ensuring optimal performance and safety during high power charging.
- user-friendly design: features such as long, retractable cables, customizable interfaces, and various payment options, which enhance the user experience [6].

2.2 Interoperability across the Complex EV HPC Ecosystem

Interoperability, the seamless integration and communication of different ecosystem elements, is crucial for the success of EV charging infrastructure. In the multi-actor ecosystem of electro-mobility, interoperability ensures that various components such as charge points, CPMSs, MSPs, and aggregators can work together efficiently.

Experience shows that interoperability and data transparency vary significantly across different interfaces. Each ecosystem player operates with distinct sets of data and communication protocols, which can complicate the integration process. For instance, the OCPP (Open Charge Point Protocol) is widely used for communication between charge posts and the CPMS. However, the implementation of OCPP varies considerably between charge post OEMs (original equipment manufacturers) and CPMSs. Similarly, roaming protocols facilitate interactions between the CPMS, aggregators, and MSP front- and backends. However, the type and granularity of information exchanged differs between systems.

OCPP is a key enabler for operations, diagnostics, and maintenance, providing a standardized method for these critical functions. However, the implementation of OCPP can vary between vendors, leading to what are known as "dialects" of the protocol, such as OCPP 1.6J (Fig. 2). These vendor-specific implementations can increase integration complexity for operators and potentially limit the quality of operations. The use of open, de-facto standards like OCPP is intended to promote interoperability, but the variations in implementation highlight the need for more uniform standards. Ensuring compatibility across a diverse set of ecosystem actors is essential for achieving a reliable and efficient EV charging network. As the industry continues to evolve, addressing these interoperability challenges will be key to supporting the widespread adoption of EVs and enhancing the overall user experience.

2.3 Vendor Error Codes as an Example of Data Quality and Data Consistency

In addition to OCPP standardized error codes, vendor error codes are important for EV charger and associated ecosystem issue/error root cause analysis, diagnosis, and subsequent resolution as they are more granular, detailed, and issue-specific compared to the standardized OCPP error codes. A prevalent industry challenge, however, is that vendor error codes are not standardized. Therefore, different OEMs have different levels, standards, and quality of error codes, error information (e.g. error descriptions), error diagnostics,

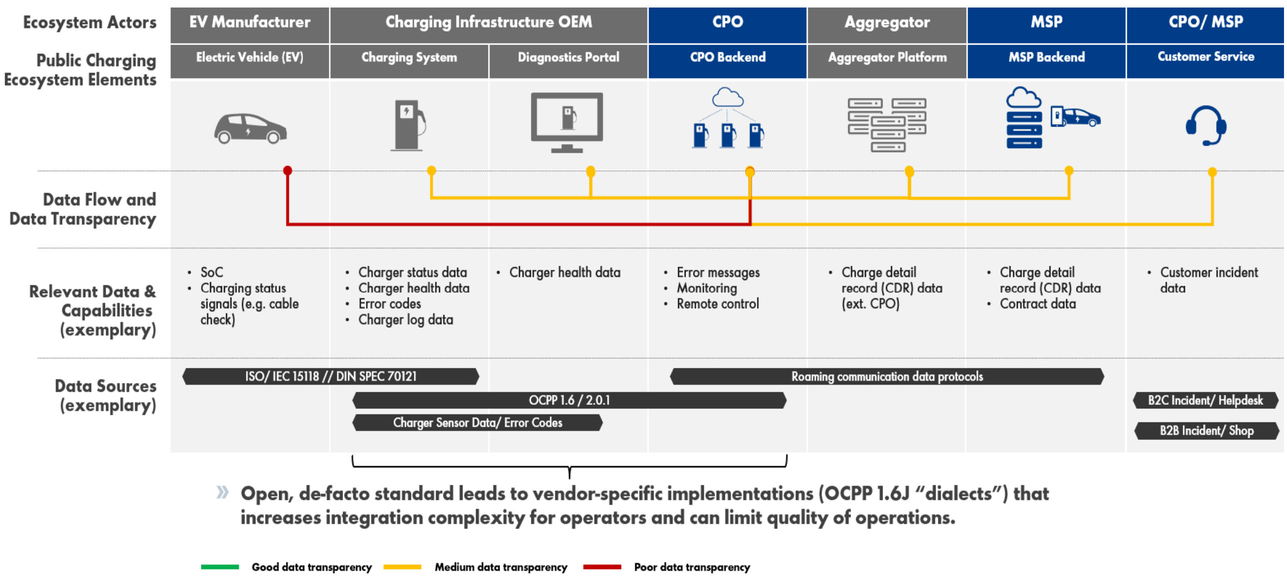

Fig. 2 Quality of data transparency across the ecosystem interfaces (© Shell plc.).

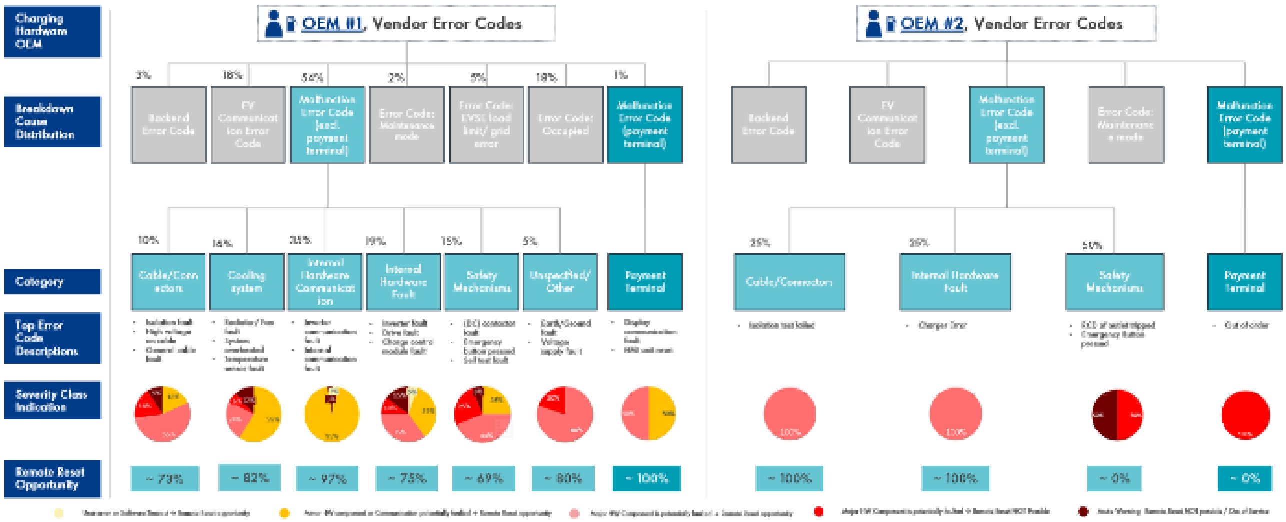

Fig. 3 Distribution of breakdown causes, malfunction categories, top errors, including severity class and remote reset opportunity. Deeper colours indicate greater severity of errors (© Shell plc.).

and suitable error resolutions. This is graphically described in Fig. 3. Furthermore, the level of vendor error code sharing by the OEMs also varies from OEM to OEM, which further adds to the complexity.

Continued improvements are being implemented via firmware upgrades and these gradually provide improvements in all aspects. However, as each OEM evolves independently, the inconsistency gap between OEMs is not reduced by these improvements.

2.4 Ticket Handling Highly Manual

In Shell, this is determined by the so-called Problem-Cause-Remedy process for issue troubleshooting/ diagnosis and resolution. Where the remedy is known and can be implemented in an automated manner, this is executed via automated tools (discussed in later sections of this paper). Where the remedy is known but automated execution is not possible, an auto-allocation is made to the relevant service vendor. The service vendor then raises a ticket/work order for the known remedy to be executed on site. Where the problem, cause, and/or remedy is not known, following an automated alert for the specific issue, a manual triaging process is carried out with relevant stakeholders across the E2E ecosystem. Once a CAP (corrective action plan) has been identified, a ticket/work order is raised for the relevant service vendor for the identified CAP to be implemented. This process is described in Fig. 4.

3. The Challenge and Opportunity ahead

To provide a compelling driver value proposition, EV charging services must be reliable, ensuring every transaction is successful and offering a seamless driver experience alongside other services. The operations and maintenance of the HPC network must be cost-effective and leverage the intelligence of the integrated ecosystem.

The technical complexity at the charge post, combined with the multitude of publicly offered authentication and payment systems, and the industry's immaturity with its concomitant lack of standards, results in numerous potential issues. These lead to a high volume of error messages triggered by technical, intercommunication, or driver handling issues, which are highly complex to diagnose as the root cause is composed of a combination of multiple failure points.

Current CPMSs offer a wide range of services for CPOs and MSPs but often do not meet the needs of facility management stakeholders. Key requirements include:

- for the operating stakeholders: improved time-to-fix, increased uptime, cost-efficiency, strategic control over facility management-related data and knowledge, and low training and onboarding efforts for new service providers.

- for facility management stakeholders: an intuitive, self-explanatory system with guided error handling functionalities, real-time error detection and alerts, remote diagnostics, vendor error code translation, guided and remote error resolution, click-to-fix and auto-healing algorithms, and, ideally, predictive features.

Fig. 5 provides an overview of features reflecting these needs and comparing their availability across software-as-a-service providers.

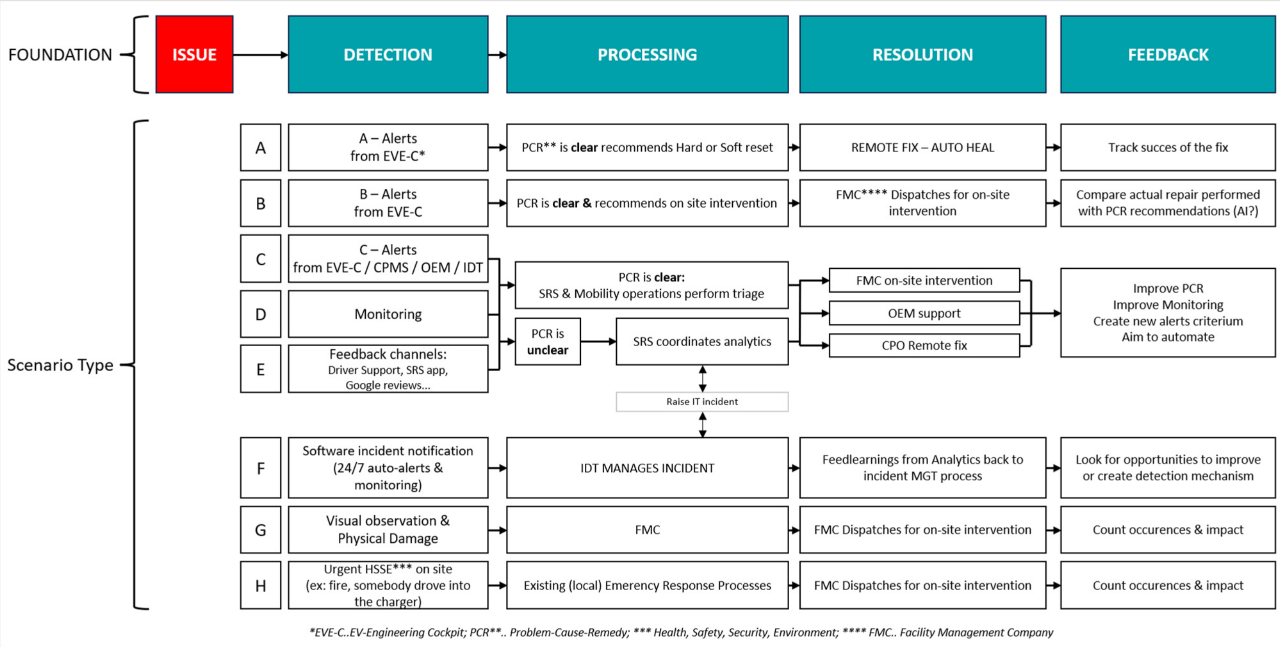

Fig. 4 Issue scenarios and Problem-Cause-Remedy process (© Shell plc.).

Epic	Theme	Features	CPMS 1	CPMS 2	CPMS 3	CPMS 4
General	General	CPMS-agnostic	Not supported	Not supported	Supported	Not supported
		OEM-agnostic	Supported	Supported	Supported	Supported
		External data integration (CPMS, Payment Terminal, Connectivity, OEM, MSP, FMC)	Supported	Partly supported	Partly supported	Partly supported
		Accessibility by various users (multiple FMCs, mobile technicians)	Supported	Supported	Supported	Supported
Uptime	Near Real Time Monitoring	Real time view of Network Health on Map as per Markets	Supported	Supported	Supported	Supported
		Overview of all chargers by current status	Supported	Supported	Supported	Supported
		Full timeline of all charger status	Not supported	Supported	Partly supported	Supported
		Full timeline of all charging attempts (Success & Failure)	Not supported	Partly supported	Not supported	Supported
		Power curves & SOC (State of Charge) to show charger power output	Not supported	Partly supported	Partly supported	Partly supported
		Full Alert History	Supported	Supported	Supported	Partly supported
		Unified view of all customer events in the charger (OCPP + PSP + MSP)	Not supported	Not supported	Not supported	Partly supported
		Full site level details (all chargers, all payment terminals, all sim cards)	Not supported	Partly supported	Partly supported	Supported
Charging success	Near Real Time Alerts	Charger Faulted Alert	Supported	Supported	Supported	Supported
		Charger Offline Alert	Supported	Supported	Supported	Supported
		Error code pattern-based alert	Supported	Not supported	Not supported	Not supported
		Low CSR charger (high probability of failed session) alert	Not supported	Not supported	Not supported	Not supported
		All resolved alerts history (last 1 year)	Not supported	Supported	Supported	No information
		E-Mail based alerts	Supported	Supported	Supported	Not supported
		Alerts for full site level issues	Not supported	Supported	Supported	Not supported
		Ability to define what action FMC has taken on the alert	Partly supported	Not supported	Supported	No information
		Full alert lifecycle - from alert generation to closure, detailing all action	Partly supported	Not supported	Supported	No information
		Visual representation of open alerts page	Supported	Supported	Supported	No information
Time to Fix	Diagnosis + Remote Resolution	Error description	Supported	Not supported	Supported	Supported
		Error categorization (hardware/power) & sub-categorization	Not supported	Not supported	Supported	Partly supported
		Guided error resolution details for remote resolution & onsite fix	Supported	Not supported	Supported	Partly supported
		Remote actions (remote reset)	Supported	Supported	Partly supported	Supported
	Auto Allocate	Auto Allocate errors to relevant support parties (FMC, PSP, MNO) based on diagnostics	Not supported	Not supported	Supported	Not supported
	Auto Fix	Automate remote actions	Partly supported	Not supported	Not supported	Not supported
	Payment Terminal	Payment Terminal (Payter) real time terminal Status and State Monitoring and Alerts	No information	Partly supported	Not supported	Not supported
	Mobile Network Operator	Mobile Network realtime connectivity status Monitoring and Alerts	No information	Not supported	Not supported	Not supported
		Results	14/30	13/30	18/30	11/30

Fig. 5 Today's CPMS solutions offer wide range of CPO and MSP service but do not meet all facility management stakeholder needs (© Shell plc.).

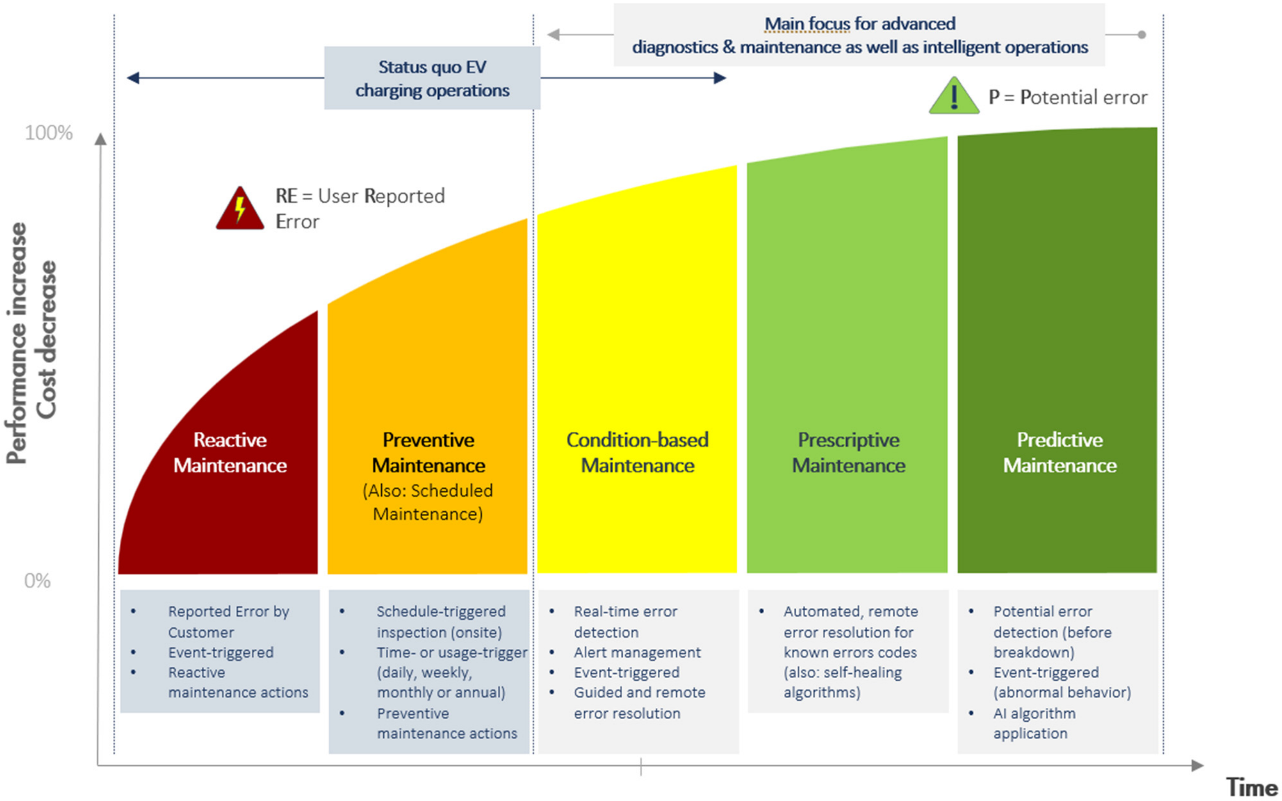

Fig. 6 Today's CPMS solutions offer a wide range of CPO and MSP service but do not meet all facility management stakeholder needs (© Shell plc.).

A platform solution tailored to meet the needs of facility management stakeholders, with superior features to support their operations and technical teams, as well as engineering needs, is essential. This ensures the ecosystem's uptime and availability, as well as a smooth driver experience.

Looking at the needs from a facility management concept perspective, we see that there are a range of facility management/maintenance concepts used in various industries to ensure the reliability and efficiency of equipment and systems, such as:

- Reactive maintenance (Run-to-Failure).
- Preventive maintenance.
- Predictive maintenance.
- RCM (reliability-centred maintenance).
- CBM (condition-based maintenance).
- TPM (total productive maintenance).
- RBM (risk-based maintenance).
- Corrective maintenance.

Looking at the EV HPC industry, the potential to apply an advanced digital-based solution is obvious. Practice, though, shows that many players in industry are instead still working on a reactive, or at most condition-based, maintenance basis. Using of a customized P-F curve [7], which we use as a mean to compare different regimes and demonstrate the journey as well as impact, visualizes the potential clearly (Fig. 6).

Facility management/maintenance and diagnostics concepts have a major impact on operating hours and resistance to error of charging hardware. Moving from "reactive maintenance" to "predictive maintenance" is a key requirement for undisrupted operations and seamless driver experience.

4. The Approach

One key opportunity to manage complex ecosystems is to understand the technical detail and establish intelligent operations solutions. We aimed to deploy "deep" and "wide" monitoring (Fig. 7) mapped to driver journeys, augmented by AI, enabling immediate and proactive action. In doing so, we progressively advance the maturity of EV charging technology operations in line with IT industry recognized maturity models and deliver the value therein.

In breaking down the task and developing a step-by-step roadmap, the Gartner Ladder [8] for maturing IT operations was used in Shell (Fig. 8).

A customized Gartner ladder for maturing the EV HPC network towards an intelligent operation is demonstrated in Fig. 9, which lists the six steps that have been used at Shell to develop an EMIO (e-mobility intelligent operation) roadmap. It starts with data identification, verification, and processing and ends with systems and tools that leverage AI and enables auto-healing and process automation of operations, including maintenance.

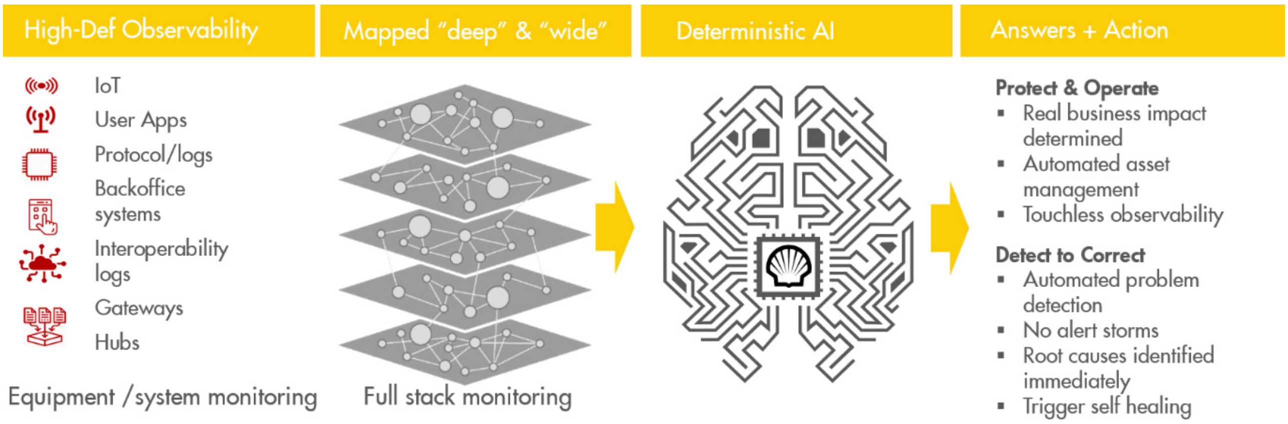

Fig. 7 From insight to action, transforming our KPIs into actionable outcomes (© Shell plc.).

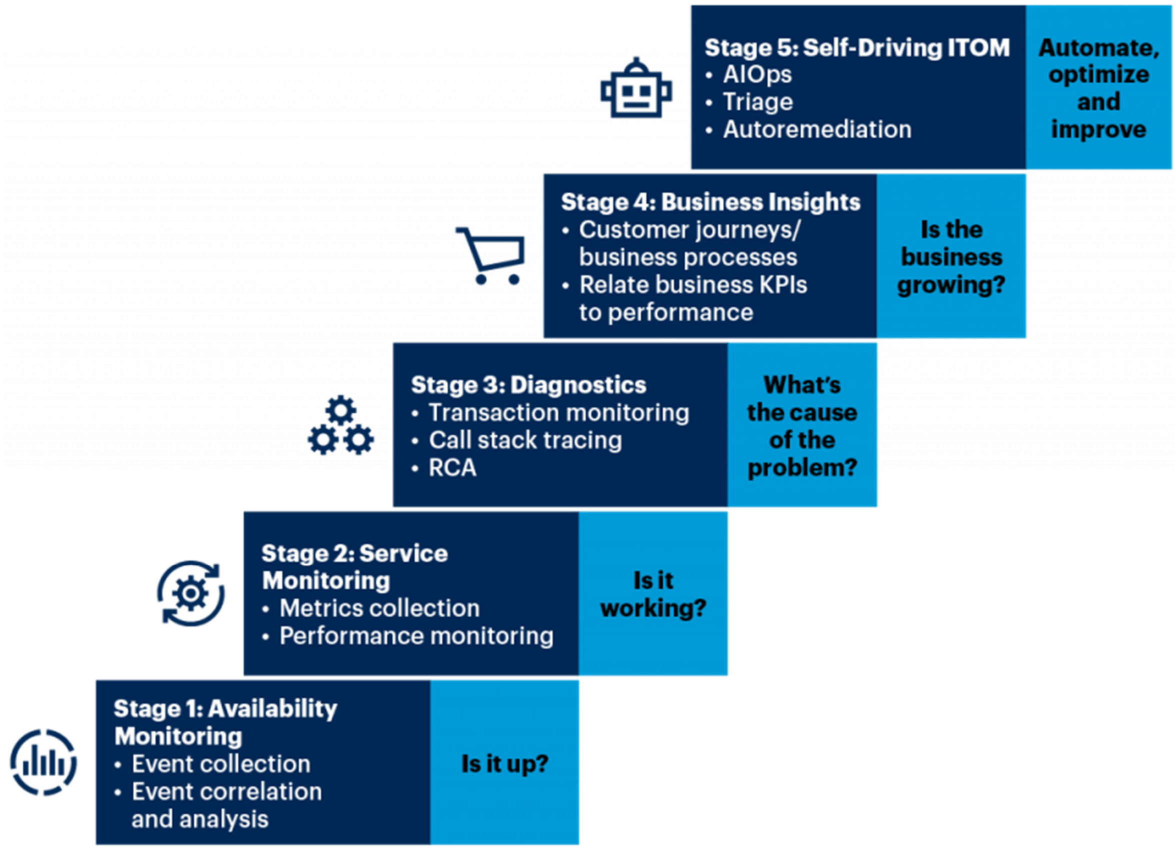

Fig. 8 Evolution of IT operations monitoring maturity [8] (© Gartner).

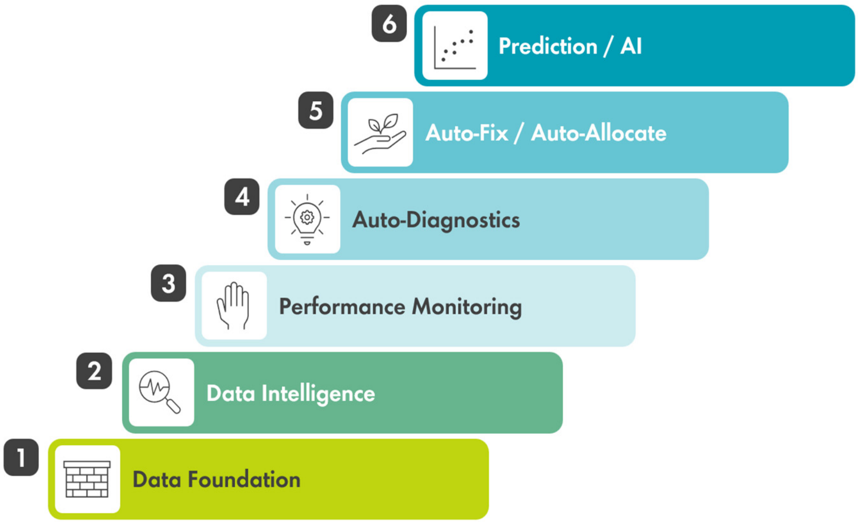

Fig. 9 Shell's EMIO ladder (© Shell plc.).

5. The Solutions

Developing along the maturity ladder toward intelligent operations requires resource investment and lining up of the many parties and systems involved into an EV HPC ecosystem (see Fig. 1). The following section describes and presents a selected set of specific solutions along the journey.

5.1 Solution—Data Requirements Framework Covering EV HPC End-to-End Life Cycle Requirements

This section describes the solution space developed to establish a data foundation. Consistent and accurate data across all elements of the EV charger E2E ecosystem are of critical importance to assess and understand the contribution of each ecosystem element to the overall charger performance as well as to carry out root cause analyses in the event of issues. Furthermore, comprehensive data from all players are critical to understand the interoperability-related complexities across the E2E EV ecosystem. A data requirement framework covering the EV charge post end-to-end life cycle requirements along with the associated improvement tools and targeted value categories used in Shell is presented in Fig. 10.

Tools already provide and enable data intelligence—the second step of the EMIO ladder.

The targeted specific data types required from some of the key players in the end-to-end EV ecosystem are presented in Fig. 11.

5.2 Solution—KPI Suite

To establish performance transparency a KPI suite has to be developed using ecosystem data and insights. Uptime, reliability, and availability—focus on uptime going forward—are traditional network operators' or asset managers' KPIs. Also, in EV HPC ecosystems, uptime is essential. Uptime can be defined as, for example, the number of seconds a connector/charge post/charge station is functional divided by the total number of seconds over the desired period. This can be broken down into several sub-KPIs, generally referring to faults or connectivity losses. Also, the aggregation of different component uptimes matters in the calculation and have to be agreed. Different formulas are in use by industry, different ecosystem players, and legislative and industry bodies.

As uptime hardly reflects the driver's charging experience, it has been realized that qualitative and quantitative measures of how successful a driver is from starting a charging attempt to finishing the charging attempt are required. In Shell, for example, the driver experience is measured using a so-called CSR (charging success rate), which is simply the number of

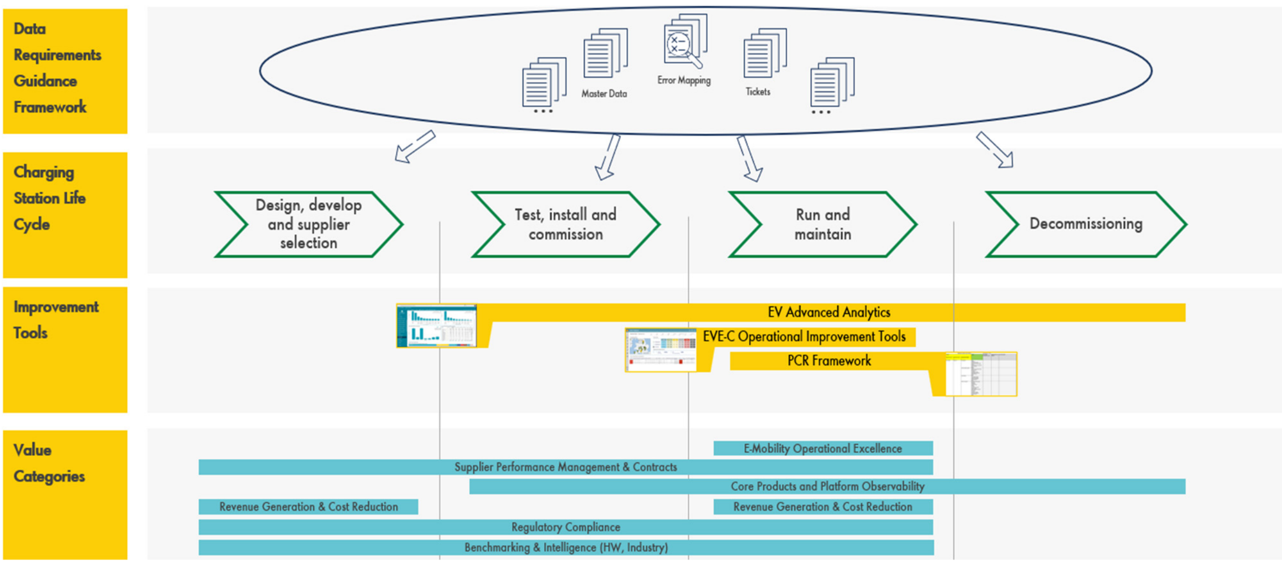

Fig. 10 **Data requirements framework across the EV charge post life cycle (© Shell plc.); "EVE-C": EV-Engineering Cockpit is a Shell Tool Name; "PCR": Problem-Cause-Remedy.**

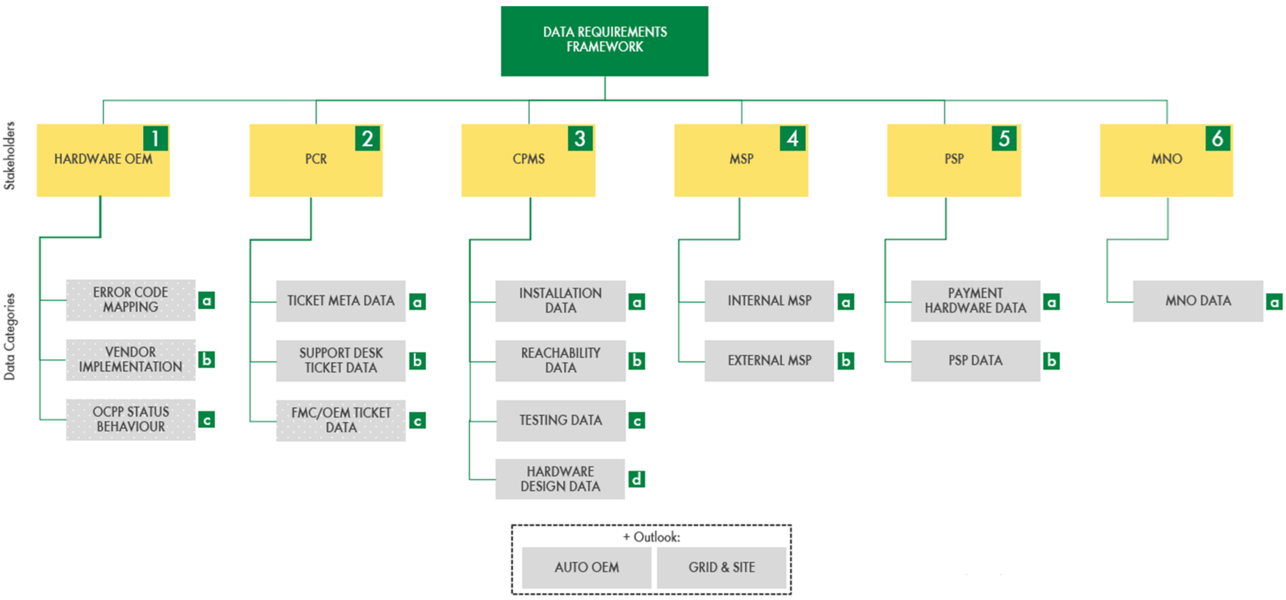

Fig. 11 **Data types of the data requirement framework (© Shell plc.).**

successful attempts divided by the total number of attempts. The measurement of a successful attempt is based on the OCPP status notification messages. The "happy flow" of statuses is Preparing-Charging-Finishing, whereas an attempt is counted as any pattern beginning with Preparing.

The KPIs and sub-KPIs can follow and be relevant for different ecosystem players or for deep-dive studies for issue resolution, e.g. time-to-fix, payment terminal connectivity, OCPP WebSocket connectivity, authorization success rate, billing success rate, etc.

Uptime and charging success have a direct impact on the number of charging sessions successfully completed and hence the CPO's revenue as well as their impact operating cost, as downtime and unsuccessful charging attempts require issue resolution. Both essentially determine profitability, along with other driver value propositions that drive CPO profitability.

Shell CSR 2.0: internally developed to measure CSR customer back (Fig. 12)!

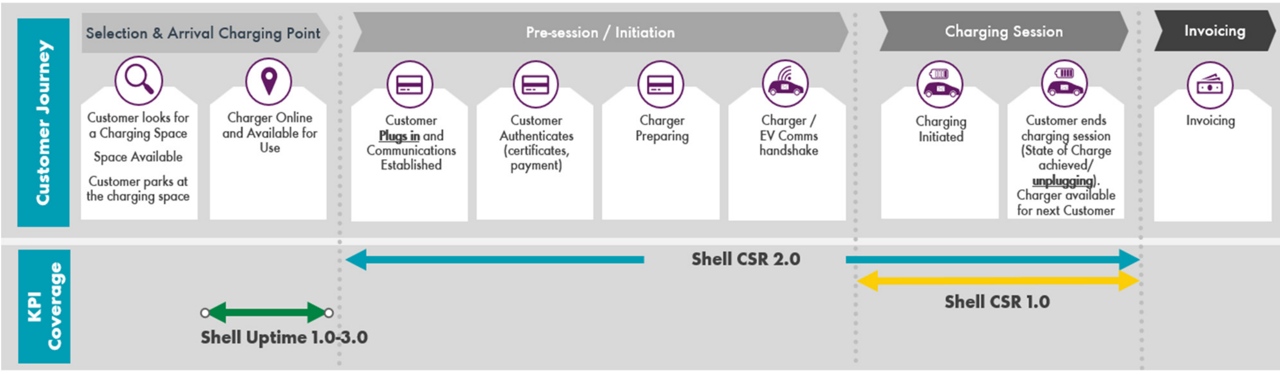

Fig. 12 Uptime and CSR KPI along the driver/customer journey (© Shell plc.).

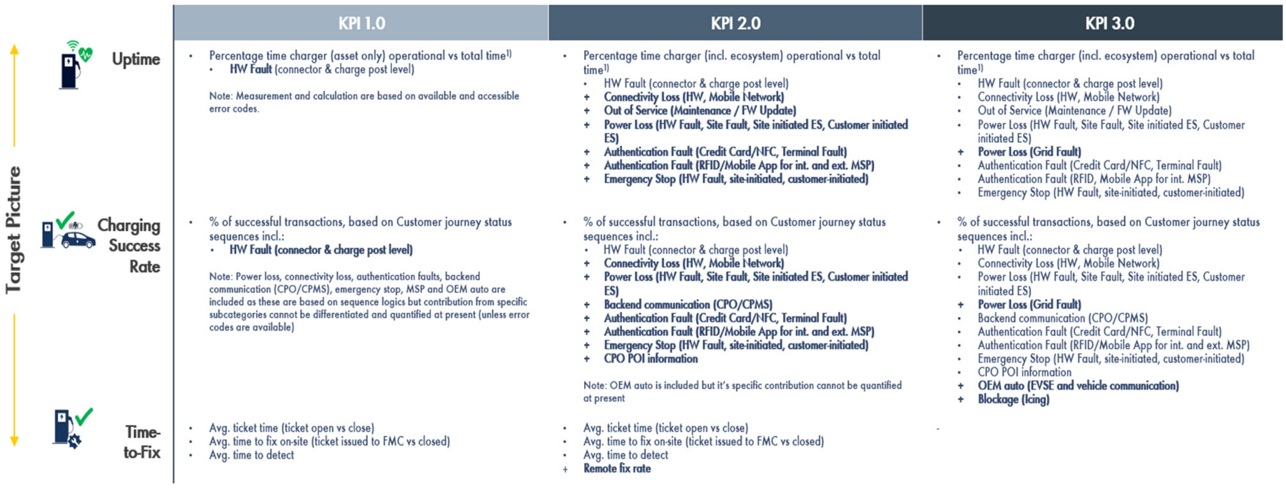

Fig. 13 KPIs and data requirements for Shell HPC performance KPI suite (© Shell plc.).

In order to develop the KPIs, the following steps are required:

- Establish data collection and management systems: Set up systems to collect and manage data accurately. Reliable data are crucial for meaningful KPI measurement [9].
- Define measurement methods and frequency: Determine how and how often you will measure each KPI. Consistent measurement is key to tracking progress over time [9].
- Define calculation mechanisms and formulas: Clearly define how each KPI will be calculated. This includes specifying the formula, the data sources, and any assumptions.
- Create a KPI reporting framework: Develop a framework for reporting KPI results. This should include who will receive the reports, how often, and in what format [9].
- Use visualization techniques: Use charts, graphs, and dashboards to present KPI data clearly and effectively. Visualization helps in quickly understanding performance trends [9].

Fig. 13 shows the data required for different KPIs and coverage in terms of the ecosystem.

5.3 Solution—Proactive Monitoring

The "EV Engineering Cockpit" shown in Fig. 14 is an internal monitoring, configurable smart alerting, and automated/remote fixing platform developed by Shell which enables proactive, preventive, and predictive maintenance across multiple elements in the end-to-end EV HPC ecosystem. This tool is utilized effectively to reduce time-to-detect and time-to-fix, which in turn increases charger uptime/availability, improves CSR, and enhances driver value proposition.

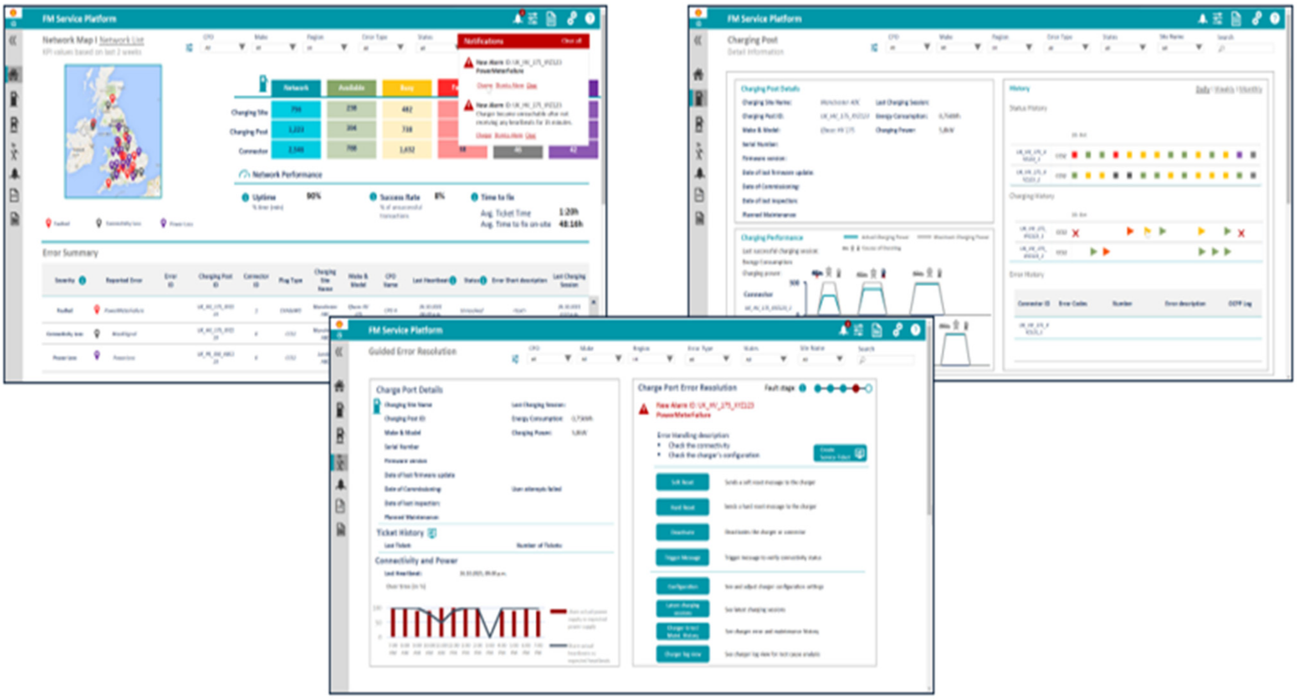

Fig. 14 Screenshots of the shell EV engineering cockpit tool (© Shell plc.).

Epic	Theme	Features	EVEC
General		CPMS-agnostic	Supported
		OEM-agnostic	Supported
		External data integration (CPMS, Payment Terminal, Connectivity, OEM, MSP, FMC)	Supported
		Accessibility by various users (multiple FMCs, mobile technicians)	Supported
Uptime	Near Real Time Monitoring	Real time view of Network Health on Map as per Markets	Supported
		Overview of all chargers by current status	Supported
		Full timeline of all charger status	Supported
		Full timeline of all charging attempts (Success & Failure)	Supported
		Power curves & SOC (State of Charge) to show charger power output	Supported
		Full Alert History	Supported
		Unified view of all customer events in the charger (OCPP + PSP + MSP)	Supported
		Full site level details (all chargers, all payment terminals, all sim cards)	Supported
Charging Success	Near Real Time Alerts	Charger Faulted Alert	Supported
		Charger Offline Alert	Supported
		Error code pattern-based alert	Supported
		Low CSR charger (high probability of failed session) alert	planned
		All resolved alerts history (last 1 year)	Supported
		E-Mail based alerts	Supported
		Alerts for full site level issues	Supported
		Ability to define what action FMC has taken on the alert	Supported
		Full alert lifecycle - from alert generation to closure, detailing all action	Supported
		Visual representation of open alerts page	Supported
Time to Fix	Diagnosis + Remote Resolution	Error description	Supported
		Error categorization (hardware/power) & sub-categorization	Supported
		Guided error resolution details for remote resolution & onsite fix	Supported
		Remote actions (remote reset)	Supported
	Auto Allocate	Auto Allocate errors to relevant support parties (FMC, PSP, MNO) based on diagnostics	Supported
	Auto Fix	Automate remote actions	Supported
	Payment Terminal	Payment Terminal real-time terminal Status and State Monitoring and Alerts	Supported
	Mobile Network Operator	Mobile Network real-time connectivity status Monitoring and Alerts	planned
		Results	28/30

Fig. 15 Shell's EV Engineering Cockpit satisfies all 30 facility/ecosystem management needs (© Shell plc.).

The tool covers all facility management needs and drives performance and cost reduction through being the frontend and enabler for automation (Fig. 15).

5.4 Solution—Auto-diagnostics, Auto-heal, and Auto-allocation

To increase uptime/availability and CSR, minimizing EV charger downtime is critical. Therefore, whenever a charger goes down, either due to a hardware fault or other issues such as connectivity and/or payment terminal failure, to name a few, rectifying these issues as soon as possible is of significant importance. Utilizing AI/GenAI-enabled digital tools equipped with smart monitoring, configurable smart alerting, and/or smart pattern recognition-based alerting coupled with auto-diagnostics, auto-healing, auto-allocation, and remote fixing significantly reduces the time-to-detect and time-to-fix of issues. Where soft/hard resets or false offline scenarios have been identified as potential resolutions for errors/issues, developing digital tools with the ability to execute automatic soft and hard resets, i.e., auto-healing, significantly reduces equipment downtime and manpower cost. Where the resolution is known but automated fixing is not possible, auto-allocation of such work orders to the relevant service vendor significantly reduces the time that would otherwise be required for manual allocation. Through the targeted Problem-Cause-Remedy concept and precise mapping of errors/issues, descriptions, diagnostics, resolutions (automated fixing) and relevant service vendors (auto-allocation of resolutions implementation), Shell has put in place an effective E2E EV charger run/maintain and performance management strategy to enhance operational efficiency, enable higher controllable uptime/availability and CSR vs. baselines, and improve its driver value proposition.

5.5 Solution—Operations Excellence via the Example of Configuration Keys

Configuration keys are a primary means by which the operation of a charger can be optimized and customized to satisfy several business and driver-specific use cases across the E2E ecosystem. In accordance with the OCPP specification, configuration keys determine the behaviour of a charger and are essential for its controllability. Some critical areas where configuration keys can have a significant impact include, but are not limited to:

- power management: through power limitation and fallback if the local connection is lost.
- distribution between several connectors to the EVs, IP address configuration for local SmartMeter and load management systems, smart charging management, etc.
- diagnostics/connectivity messaging: through heartbeat intervals, WebSocket ping/pongs, meter value sample intervals, error messages, etc.
- authorization flows and HMI configurations: through authorization methods, authorization messages, status notifications, calibrations, stop transaction requirements, time-outs, authorization cache usage, etc.
- offline behaviour: through fallback options and delay for local authorization, reconnect intervals, transaction message retries, etc.

Research and testing carried out internally in Shell across multiple use cases has shown that through targeted optimization of configuration keys, ~5%-10% improvement in controllable uptime and CSR vs. baselines can be obtained when other influencing factors in the E2E ecosystem remain the same. Standardization of configuration keys across business and driver-specific use cases is therefore critically important across all charger models being tested (i.e., prior to commissioning) and in the field (i.e., commissioned and available for driver end-use) to ensure consistency of operation, performance, and driver value proposition.

5.6 Solution—Usage of AI

Shell's Intelligent Operations Technology Strategy includes several GenAI elements in its suite of advanced analytics and operational performance management and maintenance tools. Through the ingestion of complex data from multiple internal and external sources across the end-to-end EV ecosystem into comprehensive data analysis and processing algorithms, engineers in Shell can execute detailed graphical pattern recognition and carry out targeted troubleshooting and root-causing encompassing multiple error codes, error descriptions, diagnostics, and resolutions across an end-to-end driver charging journey, thereby being able to identify where issues arise and implement rapid fixes. SMART monitoring, configurable SMART alerting and remote fixing based on auto-healing and targeted auto-allocation unified with advanced analytics data results in enhanced charger availability/uptime, reduced downtime, and successful driver charging sessions in line with the requested SoC (state of charge). The ability to analyse driver comments from feedback platforms for internal assessment using natural language processing and create associated SMART alerts keeps Shell at the forefront of driver requirements, thereby enabling the company to optimize and strengthen its driver value proposition. Therefore, it can be stated that the automation of advanced analytics and operational performance management via GenAI capabilities has been central to Shell's EV charger maintenance strategy, evolving from reactive through to a preventive/condition-based approach and subsequently to a predominantly predictive one for several charger models, topologies, and configurations.

Some AI use cases driving e-Mobilities customer experience through intelligent operations are:

- Anomaly detection: By applying AI to identify unusual performance relative to past performance and charger peers, Shell proactively detects potential issues before they escalate. This involves continuous monitoring of data from various systems to detect deviations from normal patterns. Early detection allows for timely maintenance and remediation, minimizing downtime and ensuring that charging stations operate efficiently and reliably.
- Customer feedback capture: AI is utilized to capture and analyse customer feedback through comments and uploaded images. This sophisticated analysis helps to identify issues promptly and trigger appropriate resolutions. It also expedites the identification of issues that are only detectable via physical inspection. By understanding customer sentiments and experiences in real time, Shell can address concerns more effectively, leading to improved customer satisfaction and faster resolution times. This feedback loop also provides valuable insights for future improvements.
- Configuration optimization: Advanced data science techniques are employed to identify the optimal configurations for chargers and networks. This involves analysing all the possible combinations of settings to determine the best settings that maximize first-time-right charging success. By optimizing these configurations, Shell enhances the overall performance and reliability of its charging infrastructure, ensuring that customers have a seamless and efficient charging experience.
- Root cause categorization: AI is leveraged to categorize the root causes of errors by utilizing names and descriptions from the charger OEM (original equipment manufacturer) error codes. This process provides an initial classification and guided resolution of issues, streamlining the troubleshooting process. By having a clear understanding of the root causes, Shell can implement targeted solutions to prevent recurring problems, thereby improving the reliability of the charging network.
- Root cause validation: AI is employed to validate the root causes of errors by analysing work order data from FMCs (facility management companies) and previous incidents. This ensures that the error classification is accurate and that the actions taken to resolve failures are effective. By learning from experience, this validating of root causes serves to prevent and minimize the impact of future events, leading to a more robust and dependable charging infrastructure. It also allows learnings to be shared globally.
- Smart monitoring and automated recovery: AI-driven digitalization is leveraged to enable smart

monitoring and automated recovery of EV HPC operations. By automating the processes of detecting, diagnosing, alerting, and remediating issues, network performance is significantly optimized. This proactive and intelligent approach enhances operational efficiency, reduces downtime, and improves the overall customer experience, ensuring a seamless and reliable charging network.

• Accelerated value delivery: AI-driven tools are implemented for code development and quality assurance, expediting the development process and ensuring high-quality outputs. These tools help in automating repetitive tasks, identifying potential issues early in the development cycle, and maintaining high standards of quality. By accelerating the delivery of value to customers, Shell can stay ahead in the competitive market and continuously improve its services.

Through these innovative applications of AI, Shell continues to lead the way in improving reliability and customer satisfaction. By leveraging the power of digitalization and AI, a sustainable energy future is being built.

6. Achievements and Future Outlook

Key achievements based on working on establishing an intelligent operation for HPC ecosystems are:

• Moving towards prescriptive/preventive maintenance, advanced and intelligent asset management approaches (Fig. 16).

• Improving uptime and charging experience significantly. In the case of Shell, major markets have improved their uptime by 5% and their CSR by more than 20%.

• Commercial and business value increase as costs reduce through automation and revenue increases from each additional kWh sold, as happy drivers return to a charging post again for their next charge.

• Furthermore, transparency increases and knowledge across an organization is improved as knowledge management and advancements in technology development can be made in a very targeted and structured way.

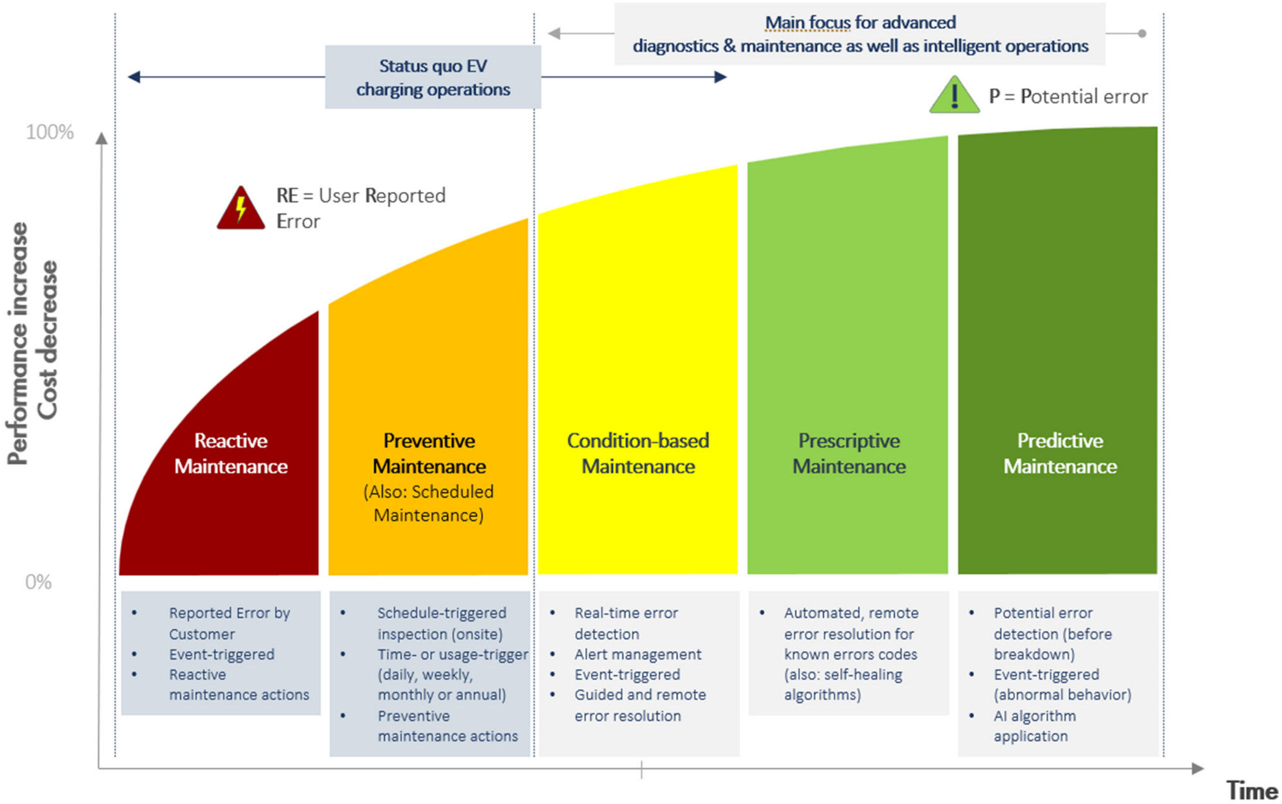

Fig. 16 Deploying an intelligent operations approach enables prescriptive and predictive maintenance (© Shell plc.).

The evolution of OCPP protocols, the importance of integrating data from non-OCPP systems and interfaces, the presence of several non-standardized OEM charger topologies, and the seamless interoperability of multiple OCPP and non-OCPP systems and interfaces within the end-to-end (E2E) ecosystem are all critical areas requiring significant attention in the near future. Additionally, the continuous evolution of legislative requirements governing how CPOs should operate and the targets for KPIs such as uptime and availability are crucial. The expected use of the OCPI (Open Charge Point Interface) for legislative requirements, coupled with the lack of clarity regarding OCPP to OCPI mapping for legislative KPI calculations, adds further complexity to the current E2E ecosystem.

Innovation in technology and its deployment at scale, such as dynamic load management, Plug & Charge, battery integrated solutions, megawatt charging and many more, may increase or decrease complexity and simultaneously multiply issue options. A maturing industry will enable stabilization and increased efficiency by promoting norms among players.

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