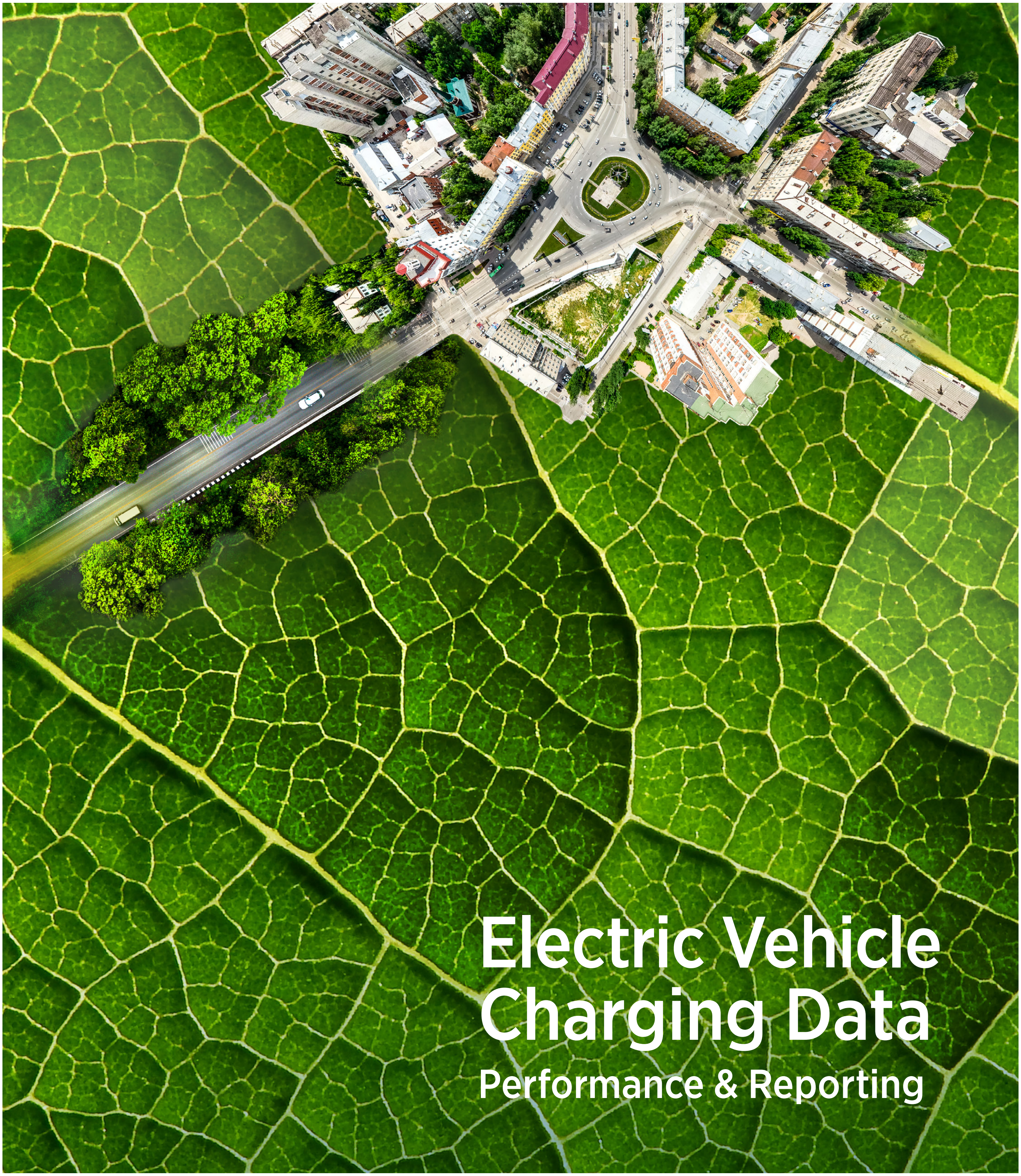
Sustainable Mobility
Solutions



Electric Vehicle Charging Data

Performance & Reporting

Sustainable Mobility
Solutions

SMSOLUTIONS0123
Issued: January 2023

CSPR FRAMEWORK TECHNICAL REPORT

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Introduction

INTRODUCTION

SAE International has long been a participant in the evolution of sustainable mobility in the aerospace and ground vehicle sectors. Our body of over 100 ground vehicle electrification standards consists of such contributions as SAE J1772, which established a standard for the conductive charging coupler used for AC and DC charging in North America. SAE's aerospace technical committees E-40 and AE7-AFC, on electrification and hydrogen propulsion, respectively, contribute to the evolution of reduced-emission air transportation. Sustainability has figured into our professional and pre-professional education programs and appears regularly in our events programming.

These efforts have centered on solving specific technical problems related to vehicle development. Sustainable mobility in cars, trucks, planes, and other vehicles depends on coordination of the vehicle to other vehicles and, more broadly, to infrastructure. It requires a transformed supply chain and the formation of new connections between manufacturers, energy companies, and government entities. Rigorous, scientific understanding of the *energy cost* of even the "greenest" form of transportation must be created to truly measure our progress. Neither the transportation industry, nor SAE, has comprehensively addressed this new, more complex, networked ecosystem and the vast scale of the change it must undergo.

SUSTAINABLE MOBILITY SOLUTIONS

In January 2021, SAE launched an initiative to define our role in this epochal shift and the capabilities we must collectively develop. We held over 100 in-depth interviews with thought leaders in the automotive and aerospace industries, energy companies, government agencies, academia, and other organizations. The feedback we received led us to create Sustainable Mobility Solutions (SMS), an innovation unit within SAE International. Its mission is **to discover, incubate, develop, and demonstrate** initiatives that lead to net-zero emission transportation.

SMS set out several operating principles:

- Contribute to creating scalable solutions to problems that affect the consumer. We work with industry stakeholders—OEMs, government, service providers, suppliers—to identify issues that directly impact the end user: whether that's an electric vehicle driver, an airline passenger, a long-haul truck operator, or others.
- Have a bias for action. Climate change is unfolding right now, and a sense of urgency to implement initiatives that mitigate its impact is critical.
- Collaborate. Climate change is a global-scale problem that involves the convergence of many systems. No single organization can be effective on its own. Collaboration is necessary to achieve impact.
- Keep human beings at the center. Although we are a scientific and technical organization, we operate in a human context. Our efforts must contribute to the improvement of life on the planet in terms of health, safety, and equality.

THIS DOCUMENT

The document you are reading is a direct result of these principles. It represents the work of a team of policy and technical leaders from over a dozen forward-leaning organizations in the ground vehicle industry and government. When asked where SMS could best apply the capabilities SAE has developed over a century, the SMS group responded without hesitation: address EV charging system failure. The group determined to aggregate charging session data with the view to create a consistent data dictionary and analysis practice. Adopting agile work practices, it studied these data, vetting and iterating its solution with the objective of producing a technical report in approximately half the time required in normal standardization. The resulting document, *EV Charging Infrastructure: Charging System Performance Reporting*, is informing work by the U.S. Department of Energy and Departments of Energy and Transportation Joint Office, as well as OEMs and suppliers.

Focusing on a discrete problem with an actionable, measurable outcome has introduced SAE International to the **world beyond the vehicle and into mobility**.

NEXT STEPS

EV Charging Infrastructure: Charging System Performance Reporting is a new type of technical knowledge creation for SAE. It is not a standard, but rather a precursor to standards: an artifact of research that defines a problem in a new area, coordinates industry cooperation, and models a technical solution. It activates other kinds of initiatives that can inform policy and regulation, research and development, and workforce training. The report situates SAE as a bridging organization between U.S. National Labs, the Departments of Energy and Transportation, the Joint Office, industry, and academia. This bridge links directly to SAE's deep history as a neutral convener.

And it is as a neutral convener that we will carry forward the work of this document. We intend to bring together stakeholders to identify, define, and organize data related to electric vehicle charging. We will publish those insights to industry, government, and the public to lead the way to more sustainable transportation, made available to all members of society.

— The Sustinable Mobility Team

Chapter One: Motivation, Problem Statement, Goals

INTRODUCTION

Consumer attraction to and adoption of electric vehicles (EVs) is accelerating worldwide. While this is due to many factors, a major reason for the shift to electric transportation is an urge to decrease vehicle emissions and their negative impacts on the environment and health. According to the U.S. Environmental Protection Agency (EPA), transportation accounted in 2020 for the largest portion (27%) of greenhouse gas emissions (GHGs) in the United States.[1] Worldwide, the figure is around 25%.[2] In the world's major cities and conurbations, the combination of traffic congestion and pollution is seriously degrading the quality of life. The calamitous effects of GHG emissions on global climate are increasingly evident.

Potential impediments to a "green shift" in transportation, centered on the adoption of EVs, include the scarcity, provenance, and cost of minerals required for EV battery production; the GHG emissions of existing electricity generation; and the comparatively high cost and weight of EVs. Nevertheless, a recent, comprehensive analysis of these key factors over a range of scenarios concludes that "full powertrain electrification makes sense from a climate point of view, and in many cases also provides reductions in TCO [Total Cost of Ownership]."[3]

For the transition to EVs to succeed and deliver the desired environmental and social benefits, electricity will have to become a practical fuel for everyday transportation. On the supply side, electrical energy systems—from large regional utilities to site-based microgrids—will have to be able to serve the new transportation loads. Electrical power generation will need to become greener and more flexible. Some believe that smaller-scale energy storage and some kind of bi-directional, transactional energy exchange capabilities will also enter into the equation.

On the demand side, public acceptance and adoption of EVs will be critical. Mainstream drivers of light-duty vehicles—the mass market that EV original equipment manufacturers (OEMs) must attract—will have to be motivated to change their orientation and habits. Early adopters have been willing to charge their EVs at home and at work on low-power stations, embracing "long-dwell charging" of 4 to 12 hours. For long-distance travel beyond an EV's range, charging needs to happen much more rapidly. EV drivers now seem to accept 20- to 30-minute stops to re-charge, but some in the industry are striving to decrease the time required to 5 to 7 minutes.

The driving public will expect to be able to charge at public facilities that are as suitable for fueling EVs as today's gas stations. They will need to be plentiful; situated in safe, accessible locations; easy to use; available when needed; and highly reliable.

MOTIVATION AND PROBLEM STATEMENT

Although industry initiative and market demand have brought EV passenger vehicle sales to an exciting inflection point,[4] scaling up EV charging infrastructure presents significant challenges. Some of these can be met by "doing more of the same, but faster/better"—like ramping up investments, improving manufacturing efficiency, or increasing charging station density or geographical coverage. Others will require focused technical innovation, such as addressing the variability of EV drivers' customer experience at public charging facilities.

Charging station manufacturers, service providers, and EV OEMs invest significantly and continuously in technical standards development, product certification, interoperability testing, and roaming platforms to meet customer expectations. However, recent studies and media coverage have highlighted the range of issues EV drivers can encounter when trying to recharge their EVs at public charging facilities.[5, 6, 7, 8, 9] Specifically, they find stations out of service; or that their charging session doesn't begin or is interrupted; or that the power delivery level is less than expected. The cause might be issues with the site's energy supply; with hardware, firmware, or software in the charging infrastructure or the vehicle; or with the interfaces or interactions between charging system components. Issues may not be communicated to the EV user or resolved timely, which can lead to frustration and dissatisfaction.

> *"Trusting that a charging station will work and knowing that, if there is an issue, it will be fixed in a timely manner, is essential to EV drivers and paramount to the success of the industry." - Kameale C. Terry, Co-Founder and Chief Executive Officer, ChargerHelp!*

There are well-known ways to provide network-connected devices with means to measure and manage their performance, and reliably deliver defined levels of customer service. The telecommunications industry (voice, data, and media service providers), with extensive experience developing open technical standards and sophisticated device and network management systems, leads in this area. Other industries, including auto manufacturing and energy utilities, are making steady progress on remote asset monitoring, data-driven service management, and incremental improvement.

EV industry pioneers built some of these capabilities into vehicles and charging infrastructure from their inception. However, these systems are entirely or largely proprietary; consequently, the knowledge and practice of delivering highly reliable EV charging service is not widespread. Indeed, **there is currently no consensus nor any open standards-based means or methods for industry, government, commercial, and consumer stakeholders to gauge the performance and reliability of EV charging systems and infrastructure**.

This is the gap in knowledge, capability, and open standards that the SMS CSPR framework project was created to address and start to fill.

GOALS OF THE CSPR PROJECT

Informed by the evolving landscape of policy and industry initiatives (detailed below), SAE Sustainable Mobility Solutions (SMS) concluded it could serve the EV charging ecosystem by leading industry stakeholders in the development of a technical framework that would allow industry to increase stakeholder understanding of charging station uptime while also addressing government and public policy objectives. Accordingly, the goals of this SAE SMS effort are as follows:

1. Engage EV OEMs and charging station providers (CSPs) in a Technical Working Group (TWG) to define a charging system performance reporting (CSPR) framework and interface.

2. Co-author and publish this technical report, the TWG’s initial proposal meant to attract further participation and technical refinement of the CSPR framework and interface.

3. Include recommendations for continuing the work, collaborating with similar efforts, etc.

POLICY AND INDUSTRY LANDSCAPE

In order to address some of the issues highlighted above, several state and federal government-funded incentive programs have included requirements for grantees to measure and report on the performance and reliability of EV charging infrastructure. In addition, there have also been other efforts across the industry to address the topic of charging station reliability. The industry members of the SAE SMS effort are aware of and engaged in many of the efforts described below, therefore ensuring the SAE SMS work is conducted within the appropriate context.

State

On the state level, the California Energy Commission (CEC) has taken the lead on uptime requirements for chargers in two 2022 funding opportunities by requiring all chargers funded under the program to be operational at least 97% of the standard operating hours of the charging facility for a period of 5 years from commissioning.[10, 11] Under the program requirements, it will be the recipient’s responsibility to demonstrate this uptime requirement is met, leaving significant room for interpretation in terms of implementation by the industry. The CEC plans to continue to address this topic area through stakeholder workshops scheduled for autumn 2022. We acknowledge there may be other state-level efforts underway on this topic not covered in this report.

In addition, Governor Gavin Newsom signed the EV Charging Reliability Transparency Act,[12] which directs the California Public Utility Commission to develop a definition of uptime (EV charging service availability) by January 2024, and recordkeeping and reporting standards by January 2025.

Federal

On the federal level, the National Electric Vehicle Infrastructure (NEVI) Formula Program funded by the Bipartisan Infrastructure Law (BIL) currently proposes each charging port meets a minimum annual uptime requirement of greater than 97% in order to receive funding.[13] The proposed NEVI technical guidance includes an uptime equation which leverages quantification of a charger’s total outage time for the year and any time that should be excluded based on events outside of the control of a charging network operator.[13] At the time of writing, the industry was awaiting final guidance from the Federal Highway Administration (FHWA) on the proposed uptime requirements. Although the proposed NEVI guidance provides additional details on how to calculate uptime, room for interpretation remains and would benefit from additional clarification around implementation to enable a scalable and consistent ecosystem of uptime reporting throughout the charging industry.

Non-Profit

From February to March 2022, a group of researchers conducted a study the availability and performance of DC fast charging stations in the San Francisco Bay Area that use the leading open standard combined charging system (CCS) connector. They published their findings on a reputable platform.[14] The study was carefully designed and executed, as documented in the published report; it confirmed the anecdotal evidence cited above in our "Observed Shortcomings" section. Here is the paper's abstract in its entirety:

> *"In order to achieve a rapid transition to electric vehicle driving, a highly reliable and easy to use charging infrastructure is critical to building confidence as consumers shift from using familiar gas vehicles to unfamiliar electric vehicles (EV). This study evaluated the functionality of the charging system for 657 EVSE (electric vehicle service [sic: supply] equipment) CCS connectors (combined charging system) on all 181 open, public DCFC (direct current fast chargers) charging stations in the Greater Bay Area. An EVSE was evaluated as functional if it charged an EV for 2 minutes or was charging an EV at the time the station was evaluated. Overall, 72.5% of the 657 EVSEs were functional. The cable was too short to reach the EV inlet for 4.9% of the EVSEs. Causes of 22.7% of EVSEs that were non-functioning were unresponsive or unavailable screens, payment system failures, charge initiation failures, network failures, or broken connectors. A random evaluation of 10% of the EVSEs, approximately 8 days after the first evaluation, demonstrated no overall change in functionality. This level of functionality appears to conflict with the 95 to 98% uptime reported by the EV service providers (EVSPs) who operate the EV charging stations. The findings suggest a need for shared, precise definitions of and calculations for reliability, uptime, downtime, and excluded time, as applied to open public DCFCs, with verification by third-party evaluation."*[14]

Public Policy

Atlas Public Policy (APP) has been engaged in data-driven research into the practical and policy aspects of transportation electrification since 2017.[15] Their work with NGOs, companies, and state and local public officials has led them to propose an EV charging use data specification, which aims to "define a common format and process for provisioning, collecting, validating and reporting on data related to electric vehicle (EV) charger deployment and use."[16] We believe our effort is well aligned with Atlas's and highly complementary.

The Atlas specification proposes metrics for multiple stages of EV charging infrastructure investment, from program design and uptake (participant enrollment and registration) through infrastructure deployment, provisioning, and use. The specification's usage metrics are most relevant to our work.[17] They are meant to gauge charging station *productivity* conceived in specific terms: the number of sessions and unique users per port or station; the total, average, and median amounts of energy delivered; and the percent of time that ports or stations are occupied, in use (charging an EV), and idle.

The CSPR framework focuses on the *performance* of EV charging systems. It describes an interface for reporting data and statistics that could inform the establishment of a range of charging system metrics, from productivity to reliability, customer satisfaction, and more. Since OEMs and charging infrastructure providers routinely collect and process fine-grained, per-session data from their vehicles and charging stations, as well as data about site conditions, device connectivity, service offerings and pricing, energy supply, etc., they are well positioned to define and refine such an interface as the EV charging industry and regulatory context evolve.

The CSPR framework project and the Atlas Public Policy charging use specification are similar in approach and technical orientation. We believe it would be fruitful to explore ways for these teams to collaborate.

GOALS OF SAE SUSTAINABLE MOBILITY SOLUTIONS AND THIS TECHNICAL REPORT

In June 2022, SAE International formed Sustainable Mobility Solutions (SMS), an innovation unit focused on helping to lead the transportation industry to net zero emissions. Although SAE has made important contributions to EV charging for years, such as the SAE J1772 standard for conductive charging, stakeholder feedback prompted SMS to extend SAE's activities beyond the vehicle to infrastructure. SMS formed a strategy council of representatives from leading OEMs, charging providers, and government entities. The group settled quickly on charging reliability as a key problem to address.

As SAE SMS's first technical undertaking, the CSPR framework project embraced an agile approach, committing to publish useful guidance and an initial technical specification within 6 months. This technical report is the fulfillment of that promise. It is the combined work of the SMS Technical Working Group (TWG) participants listed in Table 1, who volunteered to share their expertise in and between weekly meetings, and help draft the document. We are very grateful for their valuable contributions, their constructive and collaborative engagement, and their camaraderie.

Technical Working Group

NOTE: For reasons of style, this technical report will use the second-person plural voice (we, our, etc.) to express the collective work of the co-authors identified below.

Name	Affiliation	Job Title/Responsibility	TWG Role
Ahthavan Sureshkumar	Ford Motor Company	Electric Vehicle Systems Engineer	Co-author
Craig Rodine	Consultant, SAE Sustainable Mobility Solutions	Technical Advisor	TWG Chair Co-author Editor
Dan Mikat	Toyota Motor Corporation of America	Senior Program Manager	Participant
Keith Davidson	National Renewable Energy Laboratory (NREL, DOE)	Electric Vehicle—Grid Integration Researcher	Co-author
Kelsey Johnson	Rivian	Senior Policy Advisor—Energy and Charging	Co-author
Kor Meelker	ChargePoint, Inc.	Director, Global Standards	Co-author
Lee Slezak	US Department of Energy, Vehicle Technology Office	Vehicle Systems Manager, Vehicle Technologies Office	Participant
Matthieu Loos	FLO	Principal Technical Advisor	Co-author
Sarah Hipel	Rivian	Staff Systems Engineer—Interoperability SME	Participant
Walter Thorn	ChargerHelp!	Head of Product	Co-author

Table 1. Technical working group

By publishing this CSPR framework technical report, SAE SMS hopes to initiate an open and inclusive, sustained effort enabling stakeholders to collaborate on developing and validating specifications and operational principles that will meet the performance reporting needs of drivers, industry, government, public interest groups, and researchers who comprise the EV charging ecosystem.

Chapter Two: Approach and Methodology describes the TWG members' experience and expertise, and how their companies are currently collecting and using data to analyze and manage some aspects of charging system behavior. We present a CSPR framework reference architecture and data flows that represent today's EV charging infrastructure and operations, providing a basis for our design work. We then review the communication protocols currently being used between devices and systems, looking for data that could be used in a systematic way to deliver comprehensive, reliable performance data.

Chapter Three: CSPR Interface Design synthesizes the TWG members' direct experience; the anecdotal evidence referenced in our problem statement; and the Policy and industry landscape surveyed above; into what seem currently to be the "top five" issues of interest regarding charging system performance and EV driver experience. We then provide a formal specification of the CPSR interface, consisting of fields and elements designed to convey data about those five issues, which comprise an abstract data type that can be directly implemented using modern computer and data science techniques.

Chapter Four: Results and Recommendations summarizes our work and provides guidance on how the results of this project could be used for further development of practices and standards for CSPR.

TERMS AND ABBREVIATIONS

Charging Infrastructure: The hardware and software components and functions of a charging system that are not entirely contained within an EV or solely controlled by its (potentially remote) management system.

Charging System: The components and functions of the charging infrastructure and the EV involved in the transfer of energy between electrical supply and electrical load.

CSP ([Re]Charging Service Provider): An entity that provides EV drivers access to charging infrastructure. A CSP might own and/or operate charging stations (aka a charge point operator [CPO] or Charging network operator [CNO]); or it might sell or otherwise provide EV drivers access to charging stations (mobility service provider [MSP]). In North America, currently all CSPs combine the CPO and MSP roles in a single commercial entity. Several EV OEMs fulfill the MSP role only, selling their customers (EV drivers) access to services provided by CSPs. A few EV OEMs are in business as CPOs, serving their own customers only, or also drivers of competitors' EVs under specific arrangements and conditions.

CSPR (Charging System Performance Reporting): The capability that this project will define in a technical report and promote for industry adoption. In follow-on work, this capability could be implemented in prototype components enabling a proof-of-concept demonstration and the creation of a CSPR baseline measurement.

CSPR Baseline Measurement: Data gathered from an initial deployment of the CSPR framework, e.g., a proof of concept. Assessment of an eventual CSPR baseline measurement could help validate the CSPR interface and inform the refinement, acceptance, and wider deployment of the framework.

CSPR Interface: The data structure designed to facilitate the reporting of charging system performance data by CSPs, EV OEMs, and other members of the EV (re)charging ecosystem.

EV (Electric Vehicle): Any vehicle propelled by an electric motor drawing current from an RESS, intended primarily for use on public roads. (Only to those vehicles that can be charged from an external electrical source.)[18]

EVSE (Electric Vehicle Supply Equipment): Equipment or a combination of equipment which provides electric energy from a fixed electrical installation or supply network to an EV for the purpose of charging and/or discharging.[19]

GHG: Greenhouse Gas.

ICEV: Internal Combustion Engine Vehicle.

OEM: Original [EV] Equipment Manufacturer.

RESS (Rechargeable Energy Storage System): A system that stores energy for delivery of electric energy and which is rechargeable.[18, 19]

SAC: SMS Strategic Advisory Council.

SMS: SAE International Sustainable Mobility Solutions.

TWG: SMS Technical Working Group (technical advisors/co-authors from SMS SAC entities).

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Chapter Two: Approach and Methodology

SUMMARY

This chapter describes the approach the Technical Working Group (TWG) took to analyze the structure, volume, and quality of data regarding EV charging system performance that is currently collected and processed in the course of everyday operations. Also presented here is the reference system architecture that framed our analysis, which identifies and situates the essential devices, platforms, and data flows within EV charging systems that affect their performance.

This data is used by OEMs and CSPs for a range of purposes, including asset lifecycle management; EV and charging station monitoring, configuration, and maintenance; service delivery, including pricing, payment, and receipts; proof of conformance (e.g., to service level agreements or legal metrology codes); and more.

Before getting into the technical content of this chapter, we'll provide some insight into the perspectives that TWG Contributors brought to the effort.

TWG PARTICIPANTS' EXPERIENCE AND EXPERTISE

As engineers with rich experience in EV and charging station design and manufacturing, charging protocol standards, service platforms, embedded and cloud software development, and operations, we know what data is routinely collected and analyzed across the ecosystem. Detailed knowledge of and experience with standards-based communications protocols is especially relevant. While there are some useful data conveyed in those open protocols, much of the data used by industry for operational and quality purposes is exchanged, processed, and stored using proprietary means, and is not reported to outside parties in any prescribed, systematic, or regular way.[1] Thus, the TWG recognized the need for a suitable *open interface* for reporting EV charging system performance and set out to define one.

We met this design challenge by defining an abstraction from and distillation of available data sources, including charging and other open protocol specifications. While today's data sources may not be sufficient to produce all of the desired performance reporting information, we show how some elements can be used to meet several of the key requirements, and indicate how some needed data fields might be added in future versions of charging system standards.

We'll describe the currently available sources in the Data/Signals from Protocols section. We also provide some guidance on how data analysts might begin to validate our assumptions concerning the adequacy of these sources and our recommendations for processing them, in the last section of this chapter, Validating the Framework and Interface Design.

We describe the new CSPR interface in detail in Chapter Three.

Relevant Data That's Currently Used (But Not Generally Available)

Although it's not yet in the realm of Big Data,[2] the TWG was able to verify that EV charging data is currently available at sufficient volume and quality to deliver statistically significant performance data and reporting. To provide a sense of scale, we offer these disclosures from TWG members:

- One EV OEM has logged more than a million records of charging sessions for one EV model.
- Two CSPs have well over a million records of charges delivered via their stations and platforms.
- One EV OEM with multiple models deployed worldwide has a policy of collecting charging session data every time one of those vehicles is charged.
- One CSP posts on its website the number of EV charges delivered to date via its stations and service platform. At the time of publication, the count was 123 million and growing.

The CSPR interface enables entities that currently collect and process EV charging data in a proprietary way, to provide summary performance data in a format that meets public reporting and accountability requirements without exposing commercially or legally sensitive information.

ARCHITECTURE, CONSTITUENT SYSTEMS, DATA COMMUNICATION, AND EXCHANGE

This section situates the CSPR framework and interface within the larger industry context, and then focuses on the operational domain where data needed for EV CSPR is generated, collected, stored, and processed.

The Broader Context

Figure 1 shows the operational domain in relation to some "upstream" (energy supply, charging site) and "downstream" (EV driver, services market) domains. The interfaces and boundaries between these domains are fairly stable—it's important to highlight that the vast majority of charging sessions are successful. However, breakdowns in energy supply or information across domain boundaries does occasionally affect the driver experience. For example, a site might experience a power outage, or a utility demand response program might constrain or curtail energy supply for some period of the following day. The site manager or service provider would want to alert their drivers of these changes.

Other examples of inter-domain interfaces include APIs or web services between a service provider and credit/debit card processing systems, and a smartphone app that lets drivers locate, navigate to, and get service on their service provider's infrastructure.

These boundaries and interfaces have stabilized for what we might call "first-generation" use cases; e.g., public, home, and workplace charging. Other charging use cases—for example, fleet charging (fueling the EVs used for ride sharing, goods distribution and delivery)—are being developed in the "next-generation" of infrastructure build-out. Naturally, changes in technologies, markets, business, and use cases may also affect the interfaces and boundaries we currently think of as established; they will continue to evolve.

While the framework encompasses all the domains shown in Figure 1, this technical report focuses on the central Operational domain and the CSPR interface. This flagship project exemplifies SAE SMS approach of leveraging members' expertise to address the urgent need for methods and means for CSPR, while establishing the basis for further technical and business refinement of the initial effort.

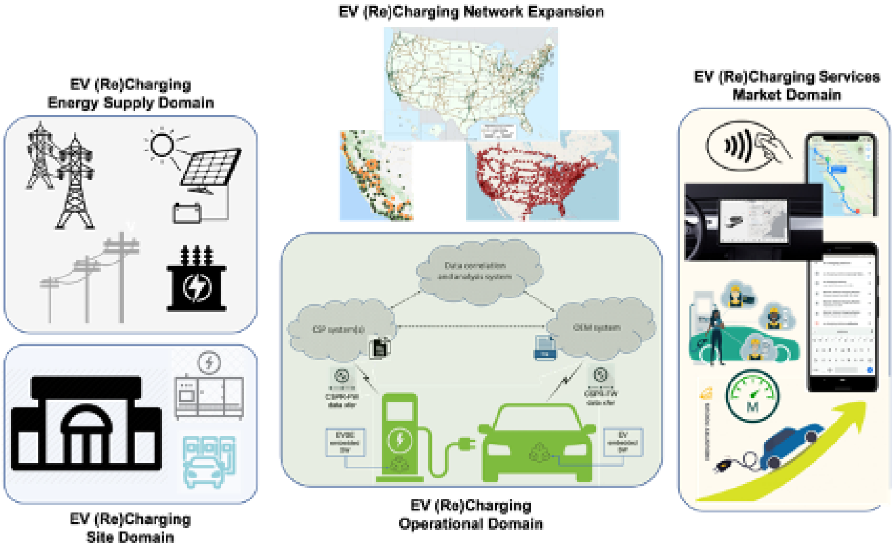


Figure 1. EV (re)charging ecosystem domains

The Operational Domain

Focusing on the operational domain, Figure 2 is an abstract depiction (reference architecture) of the systems, devices, components, and data flows of a typical charging system as implemented in North America. The EV and the charging station, also called electric vehicle supply equipment (EVSE), are the devices an EV driver interacts with directly. The other systems and interfaces shown, in particular the cloud-based remote management systems for the EV and the EVSE, support this crucial interaction. Charging system performance is a measure of how well and consistently these devices and systems, working together, deliver re-/dis-charging services to the EV driver.

Currently, the purpose of a charging system is to manage interactions between the infrastructure and/or EV and drivers for service delivery (the user interface), and interactions between the infrastructure and the EV battery (or RESS) to meet drivers' fueling needs. Charging systems and the protocols they use were designed only to deliver this service, and not to deliver data that could be used to measure and report on the *performance* (reliability, quality, efficiency, etc.) of that service. As a consequence, there are currently no open standards or descriptions of best practice for what engineers refer to as "device and system instrumentation for diagnostics." By exploring what performance reporting is possible with today's data, this technical report will identify gaps and provide direction for filling this need.

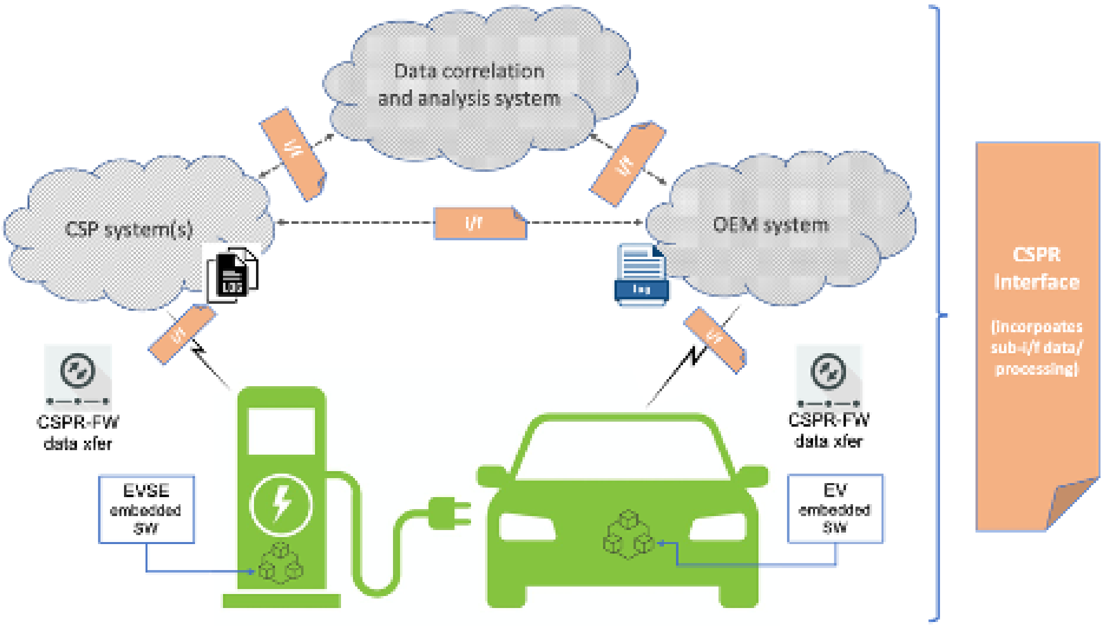


Figure 2. CSPR FW high-level reference architecture

DATA/SIGNALS FROM PROTOCOLS

This section identifies information available in standards defining communication exchanges between EV and EVSE, and between cloud-based system operated by CSPs and OEMs, that can be collected, logged, and processed to populate elements of the CSPR interface. Relevant protocol message data are briefly described, and we give indications of which CSPR interface element(s) they can inform. A discussion of how data from protocols can be processed to provide what's needed for CSPR interface-based queries and responses follows in the Protocol Data Aggregation, Synthesis, and Storage section.

NOTE: Two EV charging protocols that are widely used in North America are missing from our study. The CHAdeMO protocol is defined in published industry standard specifications, but the protocol used by Tesla EVs with Supercharger stations is proprietary and not openly available. Regardless of this difference in access to information, we were unable to cover these protocols because no CHAdeMO or Tesla engineers were able to participate in the TWG. Nevertheless, SAE SMS welcomes participation by all interested parties in our follow-on work on CSPR (see Chapter Four).

Protocol "Levels" from Lower to Higher

Protocols designed for use between a charging station (EVSE) and an EV are designed to coordinate the behavior of controllers (embedded computers and firmware) in each device. Their primary purpose is to provide signals and data to ensure that the connection between EVSE and EV remains safe, that power is delivered properly, and that any fault conditions are managed correctly. Charging protocols need to be very reliable, meaning most of the data they carry is routine and predictable; this low-level data is also exchanged frequently and becomes voluminous. For these reasons, typically only data that captures exceptional conditions (like faults or errors) is retained by the charging station and logged by the CSP. The good news is that this data is directly relevant for performance reporting.

Some routine data from low-level charging protocols is also relevant, for example messages that convey the timing of charging session events. Whether or not that data is retained and stored would depend on the CSP's operational practices and policies.

At the next level of system hierarchy, protocols like OCPP are designed to track not only charging session processes and events, but also EVSE configuration, user interactions, metering and receipts, etc. We'll see below that many OCPP data elements are directly relevant to performance reporting; what's more, the business requirements and operational practices of CSPs result in much of the most relevant data being passed from EVSEs to the cloud management system and logged. This means it should be available for processing and delivery via a comprehensive performance reporting system like the CSPR framework and interface.

Another way in which OCPP and similar EVSE-to-cloud protocols can be considered "higher level" than EV charging protocols, is that they abstract from the details of any particular EVSE. The use of such an EVSE vendor-neutral protocol is vital to some CSPs, who want to be able to integrate charging stations from many EVSE suppliers for a variety of reasons—from feature choice, to cost efficiency, and the desire to focus on software and services while partnering with hardware specialists.

In this sense, inter-network roaming protocols like OCPI are at an even higher level, since they abstract not only from the details of hardware, but also from all CSPs' specific service offerings and operations. In order to "virtualize" one CSP's stations for use by another CPS's customer, a roaming protocol needs to rely on a neutral representation of every salient aspect of the EV driver's interaction with the charging infrastructure.

Not only does this make OCPI a rich source of data for performance reporting via the CSPR interface in general, it pays immediate dividends for our current work—as will be described next.

A Key Construct: The "Charging Session"

The notion of a charging session seems intuitively clear: the EV driver navigates to a station, presents some form of identification, plugs the EVSE connector into their EV to start charging, and, at some point, the session is finished. But when, exactly, did the charging session begin and end?

The concept of a charging session is assumed or defined in some—but not all—of the protocols we'll review below. However, there is no precise definition of charging session presumed by or common to *all* charging protocols or systems. If we want to measure the (average, minimum and maximum, median) time a driver waits to be confident that their EV has started reliably charging, and compare those values between charging stations and networks, between AC and DC charging service, over time, in different locations, etc., we'll need to designate some events or state changes that define charging session start and end times. Without these, we won't be able to assess a key aspect of CSPR performance, and how it relates to driver experience and (dis)satisfaction.

Drawing on the data available at all levels, we were able to come up with a working proposal:

- Start time will be the moment when two conditions are met: the CSP has authorized service, and the connector is recognized as safely secured in the EV inlet. The first datum is available in OCPP and or OCPI messages; the second datum is available in all conductive EV charging protocols (per change in voltage on the pilot wire).

- The wait time will be the difference between the moment when energy starts to flow from the EVSE to the EV, and start time. This value is also available in all conductive EV charging protocols (per change in voltage on the pilot wire, or via digital messages).

This synthesis of data from multiple protocols operating at multiple levels, to meet a basic requirement was a happy outcome of our exploration. However, we've also discovered many ways in which today's charging systems cannot meet the goals and requirements of performance reporting. We anticipate that further work in this area will drive the evolution of charging system protocols at every level towards richer instrumentation resulting in improved diagnostics, reliability, and customer satisfaction.

Another Key Construct: "Uptime"

The notion of uptime also seems intuitively clear: it's when a charging station is fully available for the driver to use. However, there are several critical distinctions and definitions needed to allow for uptime to be measured in a meaningful way. Here are two that the TWG noted:

- What does "fully available" mean? And to which users? (Some sites might limit access to some classes of users, for some times, on some stations or ports.)
- What does "fully available" mean? What if a port is capable of delivering high power (say, 150 kW at a DC station), but delivers a maximum of only 80 kW to a driver?

Of course, the intention is to measure what percent of time a port or station is available for its intended or configured use. There is work being done in the policy community to refine the meaning of uptime; we'll simply describe a few technical features of charging systems that can help provide data that will likely enter into and such assessment.

Almost all charging stations in North America today are connected to a remote management system, typically via a wireless wide area network (WWAN; e.g., 3G or 4G cellular) service. A course measure of uptime could be determined by the percent of time that OCPP "keepalive" messages were sent and received. However, this begs many questions:

- Some of those messages could be lost, due, for example, to WWAN network congestion or outages. Would the CSP have to take account of WWAN performance in order to calculate uptime in this way?
- Some stations might have historically very reliable WWAN connectivity; it would be practical to send less frequent "keepalive" messages, which would suffice to verify connectivity. (This would help CSPs minimize their mobile network data costs, which are significant.) Would there have to be an agreed minimum frequency to establish a "quantum" for uptime messages and related measurements?

Another complicating factor: while some stations must have access to their remote management system (and thus, a WWAN connection) in order to provide service, others are designed to continue in full service (in offline mode) when their connection is lost. They might deliver service at no cost (obviating the need for real-time service authorization) or they might be able to collect payment locally and settle accounts with the drive or roaming partners when the station regains its connection. In this scenario, network connectivity is not an accurate measurement of uptime.

It would be possible, for example, to include some or all of the time the station was in service offline in calculations of uptime. Again, there's complexity: what if the station was actually out of service during that interval for other reasons? This might be recorded in its log file data, or not. The TWG explored one concept for "maximal creditable uptime period" for an EVSE delivering offline service: use metering data to calculate the interval between the start of the first charging session delivered, and the end of the last one delivered, during the time offline.

We hope this brief discussion of the ambiguities and nuances of apparently intuitive notions like charging session start time and EVSE uptime will help to convey the kind and amount of work that will be needed to develop the measurements, values, protocol data elements, data flows, and processing to deliver high-fidelity CSPR.

Protocol Data Aggregation, Synthesis, and Storage

It should now be clear that the standards, hardware and software components, networks, and systems that comprise today's EV charging systems may not have some of the capabilities we've called for in the CPSR framework. Nevertheless, as we noted under the TWG Participants' Experience and Expertise section, CSPs and OEMs currently collect significant amounts of data representing many aspects of EVSE, EV, and service platform behavior. The allocation of resources—sensing and processing power, "combing" data from charging protocols, network speed and bandwidth, cloud-based log data processing and storage—needed to support the CPSR framework and interface might not be considerably more than what is already devoted to similar diagnostics and service support capabilities in proprietary systems.

It is common for services that depend on remote devices to "over-instrument" them in their initial deployment, in order to ascertain how well subsystems perform, where issues arise, which operating parameters are most critical, etc. When the devices are performing well and operations and service delivery are stable and reliable, it's typical for service providers to reduce capital, manufacturing, and operational costs by "turning down" the volume of data collected, exchanged, processed, stored, and analyzed.

In this light, we suggest that the time and conditions might well be ripe for the EV charging ecosystem collectively to sharpen our focus and develop what's needed to deliver standardized, creditable performance reporting. Specifically, we could examine how far we could get towards the goal by modifying and enhancing the capabilities for diagnostics and service management that our devices and systems already have.

AC CHARGING PROTOCOLS: SAE J1772, IEC 61851-1

AC charging protocols do not rely on digital (packet-based) communications. Instead, they are analogue control schemes that coordinate the behavior of EVSE and EV controllers by changing voltage levels on (so-called pilot and proximity) wires in the charging cable. While these transitions constitute a charging session in the intuitive sense, that construct is not defined in these standards. The timing parameters that are specified regulate the opening and closing of relays to ensure safety, and the maximum delay allowed before energy starts flowing when service is delivered without the need for authorization. That is, how the EVSE should act as a standalone device, free for all to use without payment.

EVSEs with this behavior are deployed in North America in niche applications, like workplaces and visitor centers at state and national parks. They are a tiny portion of the installed base, and would not be able to participate in the CSPR framework.

Almost all publicly accessible AC charging stations in North America conform to the SAE J1772 standard and are managed by an embedded computer that's connected to a remote management system via WWAN. Unlike the AC charging standards, the embedded computer does have data collection and processing capabilities, and could provide data that's relevant for many CPSR Interface fields and data elements. (See Chapter Three.)

If such a network-connected AC charging station communicated with its remote management system using a proprietary protocol, we have no way of knowing with certainty what kind of data is exchanged or logged. One can only make inferences and deductions based on observation and analysis of the CSP's service logic (shown on the EVSE's display, web management portal, and smartphone app).

If a network-connected AC charging station uses the OCPP protocol, we can much more easily assess its ability to provide data for performance reporting. See the section on OCPP 2.0.1.

DC CHARGING PROTOCOLS: DIN 70121

“Top Five” Issues Reporting Data	Sub-Issue	Data	Significance
Availability (uptime)	No issue	***CurrentDemandReq/DC_EVStatus/EVReady=True*** from EV and ***CurrentDemandRes/ResponseCode=OK*** from EVSE	Charging started
	Poor network connectivity	>50% occurrence: EVSE sends ***ContractAuthenticationRes/EVSEProcessing=Ongoing*** for 150 seconds	Intermittent payment authentication timeout
	Non-responsive SECC	EV sends ***CM_SLAC_PARAM.REQ*** but EVSE does not send ***CM_SLAC_PARAM.RES***	EVSE not responding to vehicle cues
	Power module failure	EVSE sends ***CableCheckRes/EVSEProcessing=Ongoing*** for 20 seconds	Cable check timeout; EVSE unable to output insufficient voltage
Charging session data	No issue	<u>Final SOC</u>: Last ***CurrentDemandReq/EVRESSOC*** <u>Delta SOC</u>: Subtract first from last ***CurrentDemandReq/EVRESSOC*** <u>Max current requested</u>: Find maximum value of ***CurrentDemandReq/EVTargetCurrent*** <u>Max power requested</u>: Find maximum value of ***CurrentDemandReq/EVTargetCurrent* CurrentDemandReq/EVTargetVoltage*** <u>Max power delivered</u>: Find maximum value of ***CurrentDemandRes/EVSEPresentCurrent* CurrentDemandRes/EVSEPresentVoltage*** <u>Rate-limiting</u>: EVSE if (max power requested > max power delivered or max power requested = ***CurrentDemandRes/EVSEMaximumPowerLimit*** or max current requested = ***CurrentDemandRes/EVSEMaximumCurrentLimit***, else EV	Statistics to aggregate power-limiting and customer behavior based on SOC
Pricing data	n/a	Duration of ***ContractAuthenticationRes/EVSEProcessing=Ongoing***	Time for user to pay and for EVSE to recognize payment
Charging anomalies	Isolation fault	When ***CableCheckRes/ResponseCode=FAILED*** or ***CurrentDemandRes/EVSEStatusCode=EVSE_Malfunction*** or ***CurrentDemandRes/DC_EVSEStatus/EVSEIsolationStatus=Invalid***	To monitor persistent or intermittent ground isolation issues
	Low power output	If ***CurrentDemandRes/EVSEMaximumPowerLimit*** is <50% below expected max power limits	Partial power module failure
	Message timeout while charging	If EV sends ***CurrentDemandReq*** without receiving ***CurrentDemandRes*** within 250 ms, EV sends a TCP ***RST*** flag to terminate session	Poor signal-to-noise ratio or EVSE software-related hang-up
	S3 button is pressed by user	***CurrentDemandRes/EVSEStatusCode=EVSE_EmergencyShutdown*** or ***CurrentDemandRes/EVSEStatusCode=EVSE_Malfunction*** or ***CurrentDemandRes/ResponseCode=FAILED***	User has incorrectly stopped charging by trying to pull the plug connector out
Other anomalies	Precharge timeout	EV sends ***PreChargeReq*** for >7 seconds and then EV sends TCP ***RST*** flag to terminate session	EVSE precharge voltage did not satisfy vehicle voltage requirement

Table 2. DC charging protocols: DIN 70121

DC CHARGING PROTOCOLS: ISO 15118-2

“Top Five” Issues Reporting Data	Sub-Issue	Data	Significance
Availability (uptime)	No issue	***CurrentDemandReq***/***DC_EVStatus***/***EVReady***=***True*** from EV and ***CurrentDemandRes***/***ResponseCode***=***OK*** from EVSE	Charging started
	Poor network connectivity	>50% occurrence: EVSE sends ***AuthorizationRes***/***EVSEProcessing***=***Ongoing*** for 60 seconds	Intermittent payment authentication timeout
	Non-responsive SECC	EV sends ***CM_SLAC_PARAM.REQ*** but EVSE does not send ***CM_SLAC_PARAM.RES***	EVSE not responding to vehicle cues
	Power module failure	EVSE sends ***CableCheckRes***/***EVSEProcessing***=***Ongoing*** for 60 seconds	Cable check timeout; EVSE unable to output voltage
	Expired EVSE certificate	EV sends TLS alert with ***Certificate Expired*** error message	EV determines EVSE certificate is expired based on vehicle clock
	EV-EVSE certificate incompatibility	EV sends TLS alert with ***Unknown CA*** or ***Certificate Unknown*** error message	EV unable to match EVSE’s root certificate’s subject key with root certificate subject keys on EV
Charging session data	No issue	Final SOC: Last ***CurrentDemandReq***/***EVRESSOC*** Delta SOC: Subtract first from last ***CurrentDemandReq***/***EVRESSOC*** Max current requested: Find maximum value of ***CurrentDemandReq***/***EVTargetCurrent*** Max power requested: Find maximum value of ***CurrentDemandReq***/***EVTargetCurrent**** ***CurrentDemandReq***/***EVTargetVoltage*** Max power delivered: Find maximum value of ***CurrentDemandRes***/***EVSEPresentCurrent**** ***CurrentDemandRes***/***EVSEPresentVoltage*** Rate-limiting: EVSE if (max power requested > max power delivered or max power requested = **CurrentDemandRes/EVSEMaximumPowerLimit** or max current requested = **CurrentDemandRes/EVSEMaximumCurrentLimit**, else EV	Statistics to aggregate power-limiting and customer behaviour based on SOC

Table 3. DC charging protocols: ISO 15118-2

"Top Five" Issues Reporting Data	Sub-Issue	Data	Significance
Pricing data	n/a	Duration of ***AuthorizationRes***/***EVSEProcessing***=***Ongoing***	Time for user to pay and for EVSE to recognize payment
	No issue-payment selection	Value of ***PaymentServiceSelectionReq***/***SelectedPaymentOption*** (i.e., Contract, ExternalPayment)	Identify whether plug-and-charge used (i.e., contract)
	Plug-and-charge contract certificate rejected	EVSE sends ***PaymentDetailsRes***/***ResponseCode***= ***FAILED_CertificateExpired***, ***FAILED_CertificateRevoked***, ***FAILED_NoCertificateAvailable*** or ***AuthorizationRes***/***ResponseCode***<>OK when ***PaymentServiceSelectionReq***/***SelectedPaymentOption***=***Contract*** or ***AuthorizationRes***/***ResponseCode***= ***Ongoing*** for >60s when ***PaymentServiceSelectionReq***/***SelectedPaymentOption***=***Contract***	Determine whether the EV certificate was rejected or took too long to process by the EVSE
Charging anomalies	Isolation fault	When ***CableCheckRes***/***ResponseCode***=***FAILED*** or ***CurrentDemandRes/EVSEStatusCode=EVSE_Malfunction*** or ***CurrentDemandRes***/***DC_EVSEStatus***/**EVSEIsolationStatus=Invalid**	To monitor persistent or intermittent ground isolation issues
	Low power output	If ***CurrentDemandRes***/***EVSEMaximumPowerLimit*** is <50% below expected max power limits	Partial power module failure
	Message timeout while charging	If EV sends ***CurrentDemandReq*** without receiving ***CurrentDemandRes*** within 250 ms, EV sends a TCP ***RST*** flag to terminate session	Poor signal-to-noise ratio or EVSE software-related hang-up
	S3 button is pressed by user	***CurrentDemandRes***/***EVSEStatusCode***=***EVSE_EmergencyShutdown*** or ***CurrentDemandRes***/***EVSEStatusCode***=***EVSE_Malfunction*** or ***CurrentDemandRes***/***ResponseCode***=***FAILED***	User has incorrectly tried to stop charging by yanking on the plug connector
Other anomalies	Precharge timeout	EV sends ***PreChargeReq*** for >7 seconds and then EV sends TCP ***RST*** flag to terminate session	EVSE precharge voltage did not satisfy vehicle voltage requirement
	TLS issues	EVSE has sent the ***Client Hello*** TLS message but the EV has not been able to send ***SessionSetupReq***	Any TLS communication was initiated by EVSE but TLS was not established

Table 3. DC charging protocols: ISO 15118-2 (continued)

SYSTEM (DEVICE-CLOUD AND CLOUD-CLOUD) PROTOCOLS: OCPP, OCPI

OCPP 1.6-J

OCPP1.6J[5] is limited in the amount of standardized data that can be communicated to the central system with regards to the health of the charging station.

Heartbeat

The heartbeat is an empty message sent by the charging station that is responded to by the central system with a timestamp that can be used to synchronize the station's internal clock.

This message was initially used when OCPP was using SOAP to detect if the charging station was still connected. With the use of WebSocket on version 1.6J, this message is not needed.

StatusNotification

The status notification message is the standard payload to communicate status and errors on the charging station. This message can be sent at any time by the station meaning it can be during a charging session or outside of a session, the timestamp embedded in the payload should represent the time of the status changes.

The supported status are:

- Available
- Preparing
- Charging
- SuspendedEVSE
- SuspendedEV
- Finishing
- Reserved
- Unavailable
- Faulted

The supported error codes are:

- ConnectorLockFailure
- EVCommunicationError
- GroundFailure
- HighTemperature
- InternalError
- LocalListConflict
- NoError
- OtherError
- OverCurrentFailure
- OverVoltage
- PowerMeterFailure
- PowerSwitchFailure
- ReaderFailure
- ResetFailure
- UnderVoltage
- WeakSignal

Any additional information about specific components, sensors, etc., would be a “custom” error code.

The standard allows for the vendor to add as many codes as necessary via the vendorId and vendorErrorCode fields. However, the codes must be communicated to the CPO and coded which will differ between manufacturers.

MeterValue

Value from the electricity meter and other sensor can be communicated via the MeterValue message. It can be sent during a transaction for a specific connector or outside of a transaction for monitored value related to the charging station.

The supported measurands are:

- Current.Export, Current.Import, Current.Offered
- Energy.Active.Export.Register, Energy.Active.Import.Register
- Energy.Reactive.Export.Register, Energy.Reactive.Import.Register
- Energy.Active.Export.Interval, Energy.Active.Import.Interval
- Energy.Reactive.Export.Interval, Energy.Reactive.Import.Interval
- Frequency
- Power.Active.Export, Power.Active.Import
- Power.Factor
- Power.Offered
- Power.Reactive.Export, Power.Reactive.Import
- RPM
- SoC
- Temperature
- Voltage

Additional types of measurand in the MeterValue would be custom to the EVSE manufacturer.

StopTransaction

The StopTransaction message contains a “reason” field to describe how the charging session was interrupted.

- DeAuthorized
- EmergencyStop
- EVDisconnected
- HardReset
- Local
- Other
- PowerLoss

- Reboot
- Remote
- SoftReset
- UnlockCommand

This information is very limited in terms of health monitoring and does not provide much detail in case of hardware failure.

OCPP 2.0.1

OCPP 2.0.1[4] is the new version of the protocol. This version has had some significant enhancement to make enhanced monitoring and control possible.

Transactions

Where in OCPP 1.6 you had StartTransaction, MeterValues, and StopTransaction as the events for a charging session, within OCPP 2.0.1 this has been transformed into one message: TransactionEvent. This message will be used by the charging station to report every event that can take place during the charging transaction, even before the energy transfer has started. The following triggers could initiate a TransactionEvent message.

Value	Description
Authorized	Charging is authorized, by any means. Might be an RFID, or other authorization means.
CablePluggedIn	Cable is plugged in and EVDetected.
ChargingRateChanged	Rate of charging changed by more than LimitChangeSignificance.
ChargingStateChanged	Charging state changed.
Deauthorized	The transaction was stopped because of the authorization status in the response to a transactionEventRequest.
EnergyLimitReached	Maximum energy of charging reached. For example: in a pre-paid charging solution.
EVCommunicationLost	Communication with EV lost, for example: cable disconnected.
EVConnectTimeout	EV not connected before the connection is timed out.
MeterValueClock	Needed to send a clock aligned meter value.
MeterValuePeriodic	Needed to send a periodic meter value.
TimeLimitReached	Maximum time of charging reached. For example: in a pre-paid charging solution.
Trigger	Requested by the CSMS via a TriggerMessageRequest.
UnlockCommand	CSMS sent an unlock connector command.
StopAuthorized	An EV Driver has been authorized to stop charging. For example: By swiping an RFID card.
EVDeparted	EV departed. For example: When a departing EV triggers a parking bay detector.
EVDetected	EV detected. For example: When an arriving EV triggers a parking bay detector.
RemoteStop	A RequestStopTransactionRequest has been sent.
RemoteStart	A RequestStartTransactionRequest has been sent.
AbnormalCondition	An abnormal error or fault condition has occurred.
SignedDataReceived	Signed data is received from the energy meter.
ResetCommand	CSMS sent a reset charging station command.

Table 4. TransactionEvent message potential triggers

Station Telemetry and Monitoring

With the introduction of OCPP 2.0.1, it is possible to enable the monitoring features of OCCP. This makes part of the block "N. Diagnostics" of OCPP 2.0.1: Part 2—Specifications.

With this feature it is possible to capture a continuous stream of real-time telemetry data from charging stations like temperature, voltage, current, energy, power, coolant-level, faults, etc. This data can be used to monitor the stations.

Device Model

The base for the monitoring is the use of the device model. This is the new and flexible system of OCPP to send and retrieve information between the charging station and the CSMS. The flexibility within the device model makes it also the most difficult part of the new version of the protocol.

The setup of the device model can be seen as follows:

- **Device model:** Structured definition of the charging station build-up in several logical components. It is not the intention to define the complete build-of-material as your device model, but represent these components of the charging station that are of interest of the operators of the CSMS.
- **Device control:** Configuration of the charging station and its device model.
    - Controlling the way the CS and CSMS use OCPP to communicate with each other. Much of these elements play a role in the handling of the OCPP messages. (Refer to the "Referenced Components and Variables" chapter of OCPP 2.0.1: Part 2—Specifications.)
    - Enabling/disabling functionalities and features of the charging station.
- **Device information:** Informing the CSMS about the states and other measurements of the defined components of the CS. The definition of these data collection attributes of a charging station are not defined in the OCPP 2.0.1 standard. These have to be defined by the manufacturer, because they depend on the design of the charging station.

Information Exchange

OCPP 2.0.1 is defined to communicate via a request/response mechanism via websockets. This works fine if you have a more command/control relation with the charging station, but if you want to collect lots of information from the charging station, there are better ways to do this—like the publish/subscription model. Here, the charging station just publishes the information on a queue/broker and everybody that is interested in the information can subscribe on it and retrieve the information. This topic is on the roadmap of OCPP 2.1.

Large Amount of Data and Message, Higher Costs

For proactive monitoring, a lot of data needs to be collected and sent over to the CSMS. The standard way OCPP 2.0.1. is doing this makes this possible but is very inefficient. For every sampled value of a component/variable, a separate message must be sent. This message includes a lot of overhead information regarding the identification of the variable and reasoning of the information. When large amounts of information must be sent, this must be more condensed and aggregated. This topic is on the roadmap of OCPP 2.1.

OCPI

OCPI is one of the predominant roaming protocols between CPOs and eMSPs. Two major versions are currently used: 2.1.1 and 2.2.1.

The data exchanged between CPO and eMSP is for the EV drivers to be able to purchase a charging service meaning they need to be able to locate charging station, authenticate and pay.

Information Exchange

The protocol is based on HTTP with RESTful APIs using JSON payload.

Two models can be used to exchanged information; push or pull. The push model allows for better real time information to all the parties connected and less overall traffic by avoiding periodically sending request to keep the database synchronized.

Modules

The OCPI services are broken down in modules that are shared with the other parties via specific endpoints.

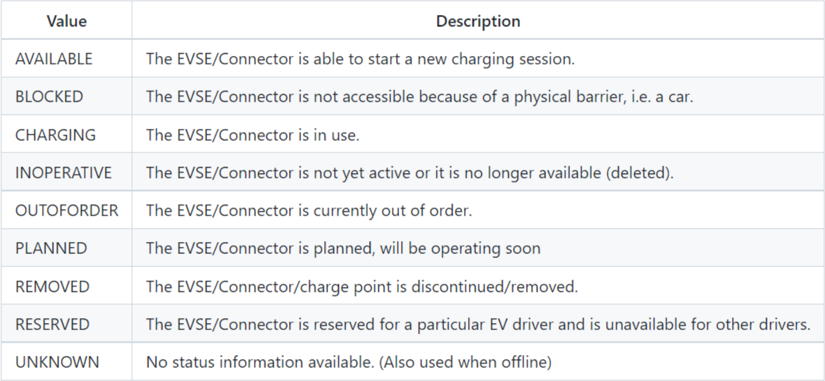
- **Locations:** Describes the charging infrastructure of a CPO.
- **Sessions:** Describes a charging session from a CPO.
- **Charge detail records:** Describes a finalized charging session, similar to a receipt for the transaction.
- **Tariffs:** Describes the cost details of the charging infrastructure of a CPO.
- **Tokens:** Describes identifiers used by EV members of eMSPs to a CPO.
- **Commands:** Enables remote command of the charging infrastructure.
- **Smart charging:** Enable load management command of the charging infrastructure (in version 2.2 and above).
- **HubClient:** Enable OCPI to be used for roaming platforms like Gireve and Hubject (in version 2.2 and above)

Monitoring and Troubleshooting

OCPI is not meant to be an advanced troubleshooting protocol but is meant to share information and synchronize database to offer access to charging infrastructure and charging services from multiple parties.

Infrastructure Status

The status of the charging infrastructure is provided at a very high-level as described in Figure 3.

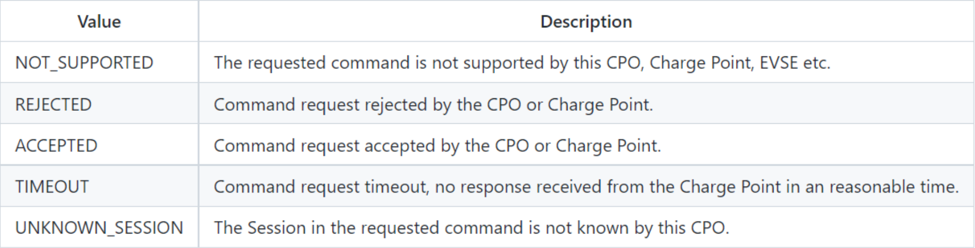


Value	Description
AVAILABLE	The EVSE/Connector is able to start a new charging session.
BLOCKED	The EVSE/Connector is not accessible because of a physical barrier, i.e. a car.
CHARGING	The EVSE/Connector is in use.
INOPERATIVE	The EVSE/Connector is not yet active or it is no longer available (deleted).
OUTOFORDER	The EVSE/Connector is currently out of order.
PLANNED	The EVSE/Connector is planned, will be operating soon
REMOVED	The EVSE/Connector/charge point is discontinued/removed.
RESERVED	The EVSE/Connector is reserved for a particular EV driver and is unavailable for other drivers.
UNKNOWN	No status information available. (Also used when offline)

Figure 3. Infrastructure status high-level overview[3]

Failure to Command

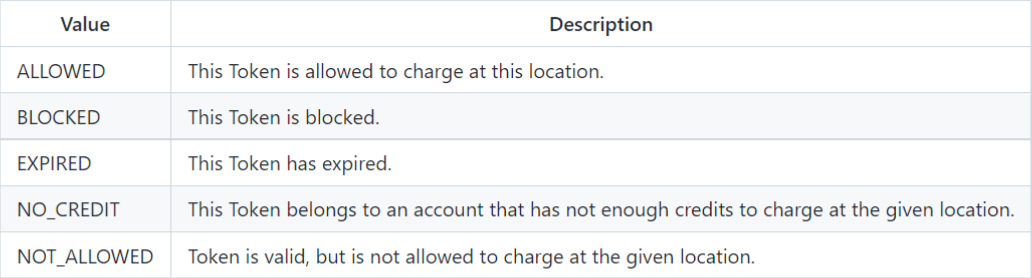
Commands from an eMSP to a CPO can fail for multiple reasons and OCPI provides some information on the reason why the session failed to be initiated.



Value	Description
NOT_SUPPORTED	The requested command is not supported by this CPO, Charge Point, EVSE etc.
REJECTED	Command request rejected by the CPO or Charge Point.
ACCEPTED	Command request accepted by the CPO or Charge Point.
TIMEOUT	Command request timeout, no response received from the Charge Point in an reasonable time.
UNKNOWN_SESSION	The Session in the requested command is not known by this CPO.

Figure 4. CommandResponseType enum (the response/result of the requested command)[3]

In the situation where the authorization request comes from the CPO, because of a RFID card scan or other local authentication mechanism, an Allowed enum is detailed.



Value	Description
ALLOWED	This Token is allowed to charge at this location.
BLOCKED	This Token is blocked.
EXPIRED	This Token has expired.
NO_CREDIT	This Token belongs to an account that has not enough credits to charge at the given location.
NOT_ALLOWED	Token is valid, but is not allowed to charge at the given location.

Figure 5. Allowed enum[3]

Functional Behavior

In addition to technical monitoring, the behavior of the functional modules could have their influence on quality.

Authorization and Tokens

When a charging session is started at the EVSE, the CPO first will want to authorize the presented RFID-token, to guarantee the payment of the charging session. For this, the CPO uses the tokens that are provided by the MSP. This can be done via WhiteListing or Realtime Validation. Both will make use of the token-module of OCPI. In both cases, the tokens will be send to the CPO by the MSP. This way, the CPO knows the tokens and knows how to behave when a RFID-token is presented at the EVSE. The whitelist contains the unique RFID-token ID, indicates which MSP is responsible for the contract and billing handling, and indicates how the authorization process has to be done.

Whitelisting is the simplest process. Here, the CPO has the complete list of tokens available in its own back office and can verify the token via a simple database action. To have this working correctly, it is important that any change in validity of the token should be directly reported by the MSP and processed by the CPO in its database.

Realtime validation is a bit more complex. After finding the token in the whitelist database, the CPO has to ask the MSP if the token is valid to be used for the requested charging process. Depending on the answer, the session will either start or not. This process relies on a 24/7 availability of the MSP back office. When this is not the case, OCPI provides processes for how to act when the connection is offline.

Remote Start/Stop

Starting a charging session can also be done via the app that has been provided by the MSP. Here, the authorization is done by the MSP and, if okay, the request for starting the charging session is sent via the commands module. When a CPO receives this request, they will assume that the charging has been authorized and will forward the request towards the EVSE, who will then start the charging. To stop the charging session, the stop command will be forwarded via the commands module.

Other OCPI Modules

The other OCPI modules are not used to directly control the charging process, but are used by the CPO to provide information about the locations of the EVSEs and their tariffs in general. They also provide more specific information about the progress and control of the charging sessions.

VALIDATING THE FRAMEWORK AND INTERFACE DESIGN

It would seem to be a straightforward exercise for CSP engineers and data scientists to analyze the data they currently use for (e.g., operational or quality purposes) to determine how well it would fit into the open performance reporting framework and interface we're exploring in this technical report. Efforts towards validating or improving the approach we've take in this technical report, or guiding our ongoing work on CSPR, would be welcome and appreciated.

CHAPTER TWO REFERENCES

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3 OCPI. (2021). OCPI 2.2.1: Open charge point interface. *EVRoaming Foundation*. Retrieved from https://evroaming.org/app/uploads/2021/11/OCPI-2.2.1.pdf.

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Chapter Three: CSPR Interface Design

SUMMARY

Our goal is to provide a technical framework enabling the collection, processing, and delivery of data that characterizes charging system performance. At the center of that framework is the CSPR interface, which we describe in detail in this chapter.

Our design is meant to serve first and foremost as a flexible, extensible technical foundation for CSPR. The main goal is to facilitate reporting by ecosystem participants (OEMs and CSPs, initially) on the full range of performance, from normal, sustained infrastructure operation to abnormalities that can diminish the EV charging experience.

In order to demonstrate the applicability and value of the CSPR framework, we defined the first instance of the CSPR interface to deliver information that we believe will be immediately relevant to and useful for the broad range of EV charging ecosystem participants. These highlight what we refer to as our "top five" issues of interest.

IDENTIFYING AND VALIDATING THE "TOP FIVE" ISSUES OF INTEREST

As noted in Chapter One, a number of service quality issues have been frustrating EV drivers, resulting in the press accounts cited under observed shortcomings. The CSPR interface needs to be able to report data that describes the nature, frequency, and severity of such issues. Also of interest is data reflecting other aspects of the EV charging experience, such as amounts of energy delivered and service pricing.

Drawing on anecdotal evidence and more importantly, on our direct experience of EV charging service delivery (see TWG Participants' Experience and Expertise) we've crafted our initial version of the CSPR interface to deliver data[1] on these performance factors:

1. Service availability (SA) (uptime)

2. Charging session (CS)

3. Service pricing (SP)

4. Charging session anomalies (CSA)

5. Other anomalies (OA)

CSPR INTERFACE: REPORTING DATA ABOUT THE "TOP FIVE"

Overview

The CSPR interface is a conceptual or abstract data type[1] meant to organize and facilitate the collection, processing, encoding, storage, and retrieval of charging system Performance data. These five functions, when completely defined in a formal data model, would comprise a complete reporting system.

By positing the CSPR interface as an initial design for data exchange between consumers and producers of CSPR data, we aim to provide a useful starting point for further development of the technical core of the CSPR framework. See Chapter Four for our recommendations on ways to continue the work and incrementally refine the framework and interface.

Options for implementing the abstract CSPR interface design in an operational system using well-known techniques are reviewed in the section on System/Platform Level Considerations section.

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[1] We've deliberately chosen the term "data/statistics" rather than "metrics." The former denotes "mere" measurements, while the latter connotes a means of comparing measurements to gauge performance, which (means) proves to be useful. At this stage of CSPR framework development, we don't yet know what metrics will be the best figures of merit for EV charging, whereas we do know how to collect and report data. Thus, our choice of the humbler term. Nevertheless, as the framework evolves and we gain experience with these data and statistics, the interface should deliver proper metrics (so we'll leave "performance" in our name to reflect our aspiration and ultimate goal).

The CSPR interface data type, including metadata and data reporting fields, is depicted in Figure 6. In the rest of this section, we'll describe the interface in seven subsections. The first explains how the CSPR metadata is used to describe the data contained in the other fields. The next subsections explain how interface fields are used to report on the "top five" issues listed above, and describe their constituent elements. The last subsection defines the CSPR-specific data types we've defined for use across all CSPR interface fields and elements.

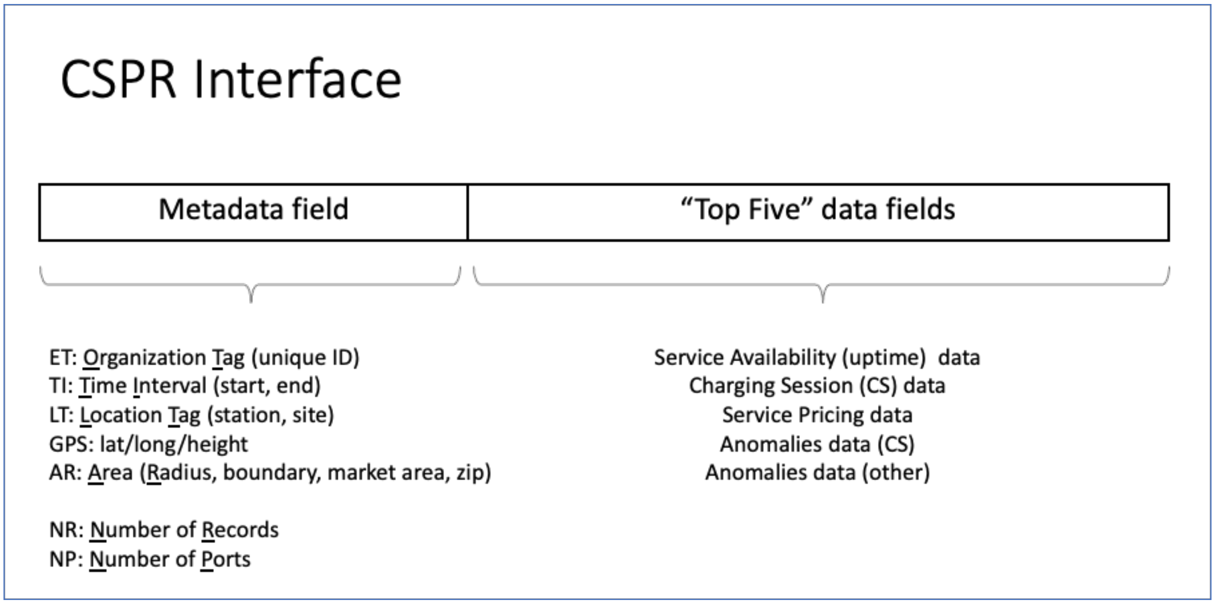


Figure 6. CSPR interface

Metadata Field

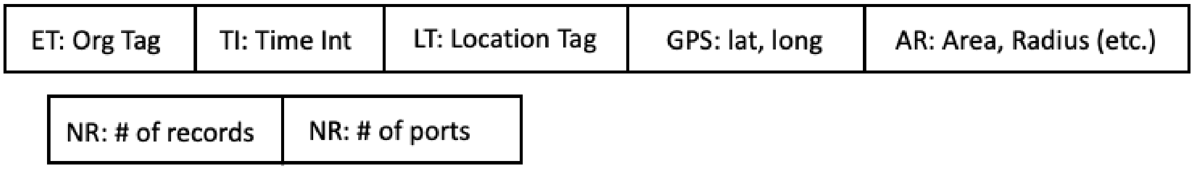


Figure 7. Metadata field elements

The elements in the metadata field describe what the data in the "top five" fields represent. The primary purpose of the Metadata field is to represent the content of the other fields; however, it also provides a basis for structuring database queries for retrieving and reporting charging system performance data.

The first five elements of the metadata field would be suitable for use—in some combination, perhaps with some constraints—to form search queries (i.e., input to a reporting system). The last two elements would be useful for reporting the number of service events and service points the statistics returned in "top five" data fields represent (output from the reporting system).

It's important to note that the CPSR interface is an abstract representation; the details of search logic are a separate concern. There are many choices for how queries might be formed and what responses would result. For instance, some metadata elements or a subset might be required as query input; some might take precedence over or override others; some elements could be used as input, or limited to output, or serve as both.

As an indication of how metadata fields could be used in database queries and responses, we include some exemplary search interactions in the Abstract Search Examples Based on the CSPR Interface section. Some further thoughts on search logic and implementation are provided in the System/Platform Level Considerations section.

Table 5 shows the data type definitions of all the elements in the metadata field. (CSPR Object types gps_locations, tags, and time_interval are described in the Foundational Datatypes (CSPR Objects) section.)

Element Name	Data Type[5, 6, 7, 8]	Description	Comments
ET: Entity Tag/s	tags	Name of data producer.	Must be unique, e.g., org ID in SAE PKI.
TI: Time Interval	time_interval	Date-time of first and last service delivered.	Initially, one time interval for simplicity (could be expanded, e.g., to an ordered set of intervals).
LT: Location Tag/s	tags	Name(s) of service sites/stations.	A structured string, should be unique (see Table 12).
GPS: lat, long, (height)	gps_locations	GPS coordinates of a point or area anchor.	Per ISO 6709 or WGS84 (see Table 11).
AR: Area (Radius, boundary, CDP, market area, zip code)	Object {float, object, string}	Area or region where service was delivered.	Only radius is understood well enough at this point; definition of the other area types TBD.
NR: Number of service records	Number (integer)	Number of service records (e.g., charging sessions) represented.	A non-negative integer (≥0).
NP: number of service points	Number (integer)	Number of service delivery points (e.g., charging ports) represented.	A non-negative integer (≥0).

Table 5. Metadata element data types

Service Availability (SA) Field

Figure 8. SA field elements

The elements in the SA field deliver data concerning a critical aspect of EV charging infrastructure performance: how often charging stations are available for use, meaning fully operational and usable by drivers to charge their EV batteries during times of stated public availability.

As noted in the Motivation and Problem Statement, some state and federal government programs require EV service providers to demonstrate prescribed levels of charging service availability to qualify for incentive funding. The SA field of the CSPR interface is designed to facilitate such reporting.

In Chapter Two, we discussed methodologies for using data from communication protocols like OCPP and other sources to measure and report charging infrastructure uptime data. We noted that since there is presently no consensus around (nor open standards for) accomplishing this, proving compliance with uptime requirements would require auditing of data collection and processing. When consensus is reached on how to ensure the accuracy and veracity of uptime data, the CSPR framework and interface will accommodate reporting of that verified data, or it can be refined or extended as needed. Specifically, the CSPR framework anticipates the need for establishing trust and accountability in charging system performance data collection, processing, and reporting, as discussed in the System/Platform Level Considerations section.

Table 6 shows the data type definitions of all the elements in the SA field.

Element Name	Data Type[5, 6, 7, 8]	Description	Comments
SA_TT: Total Time	time_quantity	Total service time represented.	Equal to metadata TI [end date_time - start date_time].
SA_OT: Outage Time	time_quantity	Outage time represented.	Amount of time within metadata TI that service was meant to be available, but was not.
SA_ET: Excluded Time	time_quantity	Excluded time represented.	Amount of time within metadata TI when service was not meant to be available.

Table 6. SA element data types

Charging Session (CS) Field

CS_ST: service type	CS_IT: initialization time	CS_AA: authorization	CS_ED: energy delivered

Figure 9. CS field elements

The elements in the CS field deliver data representing the overall performance of the charging station, and of the EVs that utilize the station for charging. Four aspects of system behavior pertaining to charging sessions are represented by CS field elements, as shown in Table 7.

The first element, service type, indicates whether a port (connector) on the charging station delivers AC or DC service, and at what maximum power level.

The second element, session initialization, provides data on how long EV drivers had to wait for energy delivery from the moment when the charging cable (connector) was inserted and authorization was complete. The elements reports minimum, maximum, average, and median session initialization times.

The third element, session authorizations, reports on the number of times the authentication and authorization process succeeded and failed, for each of four methods: smartphone app, credit card contact or swipe, presentation of an RFID card, and digital certificate-based authentication.

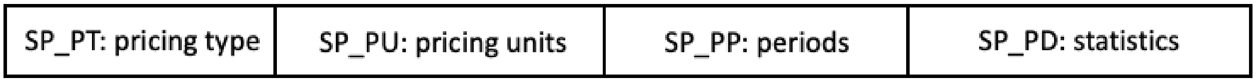
The fourth element, energy delivered, provides data on the minimum, maximum, average, and median amounts of energy delivered per charging session on the charging ports selected for reporting.

Table 7 shows the data type definitions of all the elements in the CS field.

Element Name	Data Type[5, 6, 7, 8]	Description	Comments
CS_ST: Service Type data per port	service_type	Type and level of service on a port.	See description in Table 11.
CS_SI: Session Initialization data	Object {Number:float} [4]	Minimum, maximum, average, and median time elapsed from start-of-session to start of energy flow.	Range of times drivers waited to know charging sessions began without issue.
CS_AA: Session Authorizations data	Object {enum (APP, CC, RFID, PNC), Number:int, Number:int)	Number of successful and failed authorizations (including authentication) per AA type.	Numbers of successful and failed AAs; should equal the NR in metadata.
CS_ED: Energy Delivered	Object {Number:float} [4]	Minimum, maximum, average, and median values of energy delivered per session.	Range of energy (kWh) dispensed by charging infrastructure.

Table 7. CS element data types

Service Pricing (SP) Field



SP_PT: pricing type	SP_PU: pricing units	SP_PP: periods	SP_PD: statistics

Figure 10. SP field elements

Drivers, regulators, researchers, and others would like to be able to understand and follow EV charging service pricing and trends. There are many factors affecting how much drivers have to pay for electricity as fuel for transportation, and they're bound to change as the market and supplies evolve. The legal metrology community has put initial codes in place to ensure the public benefits from commodity and service price transparency and accountability in EV charging, as they do in other areas of commerce. The CSPR interface SP field can support this critical aspect of public acceptance and adoption of EVs and public charging infrastructure.

One EV driver recently shared on social media that they've recorded the per kWh price they paid for EV charging over 2 years, providing electricity for more than 130,000 miles of driving. They noted that the CSP had "dramatically raised the price of [charging]" and opined that "drivers are no doubt feeling the pinch."[2]

The SP field can provide such data for any station, operator, location, time period, etc., of interest.

Table 8 shows the data type definitions of all the elements of the SP field.

Element Name	Data Type[5, 6, 7, 8]	Description	Comments
SP_PT: Pricing Type	Enum (kWh, Min, Fixed, Other)	Type of pricing: per kWh, per minute, fixed (flat) rate, other.	This covers only basic pricing types. Should be expanded to meet all pricing and fee types in use, e.g., one-time access fees, parking fees, roaming fees, taxes, etc. Should be aligned with other codes and standards pertaining to service pricing, e.g., HB44, OCPI.
SP_PU: Pricing Units	currency_type	Currency in which pricing is shown to the user.	Three-letter currency symbol per ISO 4217, but see SP_PD: Pricing Data for representation of monetary value.
SP_PP: Pricing Periods	pricing_periods	Periods when pricing types and values (rates) are in effect.	Similar to utility rate plans, which describe per-unit price during multiple time periods, e.g., weekdays and weekends. See Table 12.
SP_PD: Pricing Data	Object {String} [4]	Minimum, maximum, average, and median values of price per charging session.	Per ISO 20022 CurrencyAnd30Amount: up to 30 total digits, up to 10 fraction digits, separated by a dot. Allows for prices with sub-cent values, e.g., EUR 0.45125 (per kWh). Full-cent values can be per ISO 4217, e.g., USD 0.33 (per kWh); JPY 50 (per minute), CAD 25 (flat rate).

Table 8. SP element data types

Charging Session Anomalies (CSA) Field

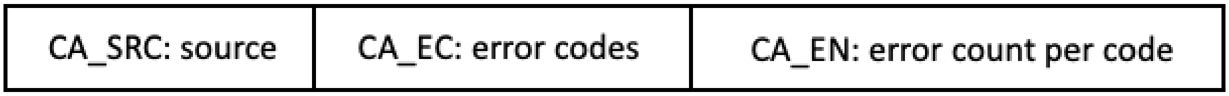


Figure 11. CSA field elements

As we demonstrated in Chapter Two, protocols used for the EV charging process, for charging station and service management, and for inter-network roaming carry data that can be used for performance reporting. We noted that protocols used for DC charging coordinate the EV's charging safety and battery management functions with the corresponding safety and power conversion/delivery functions in the charging station. And that these protocols include some error codes that can be used to record faults that occur during DC charging sessions.

The elements of the CSA field can report the type and frequency (count) of those error codes, and similar data from other protocols that indicate how the charging process was interrupted or otherwise failed.

The error codes currently available, and the conditions they describe, are not adequate for thorough performance reporting. Like all fields of the CSPR interface, the CSA field is extensible so it can be adapted and refined as the diagnostic capabilities of EVs, charging stations, and protocols in the scope of the CSPR framework evolve.

Table 9 shows the data type definitions of all the elements of the CSA field.

Element Name	Data Type[5, 6, 7, 8]	Description	Comments
CA_SRC: Source	Enum (EV, EVSE, CSP)	Device or entity that reported the anomalies.	A single value. Could be expanded to support error codes from multiple sources, e.g., that are correlated.
CA_AC: Error Codes	Object {String} [1..M]	Array of anomaly codes indicating error or fault condition reported by CA_SRC.	These strings need to be structured following a scheme for categorizing charging system errors. There is currently no standard offering examples or guidance for system-wide error categorization or correlation.
CA_AN: Error counts	Object {Number: integer} [1..M]	Array of number of error code instances reported by CA_SRC (per CA_EC array element).	Error code counts could be stored with array codes in the same N-ary list or array.

Table 9. CSA element data types

Other Anomalies (OA) Field

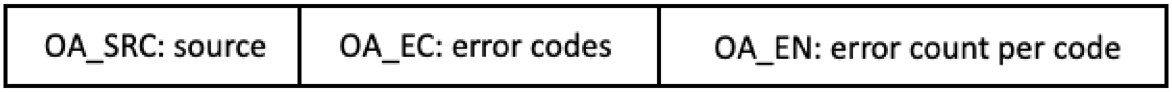


Figure 12. OA field elements

We've included a field for OA in order to "hold a place" for this important component of charging system reporting. Elements in this field report issues with EV charging that are not represented in the charging session (CS) and charging session anomalies (CSA) fields.

For example, OA could include data indicating physical damage to stations or connectors, unadvertised closures; barriers to access, etc.

Examples of physical damage could include cut or damaged cable; broken connector (damaged housing, pins, or retainer clip); damaged screen or payment device (credit card or RFID reader). Many of these issues are discovered by EV drivers who navigate to charging stations expecting to re-charge, and find them unusable. Many CSPs provide ways to report such issues on their app or via phone support, but drivers might not be motivated to help when they're inconvenienced, frustrated, or worse (e.g., stranded because they don't have enough range left to go to another charging station).

OA field elements might also capture or be relevant for issues that can have an impact on charge station reliability over time, especially as the installed EVSE and EV fleet ages. For example, impedance of the charging circuit to ground has been identified as such a parameter.

The SAE J1772 standard requires all EVSEs to monitor isolation between rails and ground and terminate a charge session if the isolation value falls below a specified level. This information is not obtainable through remote communication from existing EVSE, and is not communicated to charge station/EV users, which might prompt a user to request service for the station or vehicle. More robust reporting of charging station output isolation, preferably correlated with vehicle data, would be useful for monitoring the health of EV fleets and charging networks. Such data could be reported using the OA field until incorporated as a requirement in other standards. Cable damage is also potentially measurable via impedance; some station maintenance service providers are working with manufacturers and CSPs to explore means of incorporating impedance measurements into station telemetry.

Currently, the type and amount of data that a charging station or CSP can provide regarding physical damage or other anomalies are limited. Since performance reporting is not yet required, investments in the sensors, data processing capabilities, and network service required to "instrument" charging stations and EVs for this purpose have been up to the discretion of OEMs, service providers, and equipment vendors. As performance reporting requirements emerge that strike an equitable balance between cost (to industry parties) and benefit (to drivers and society, but also to industry; e.g., for product reliability and customer satisfaction purposes), the EV charging ecosystem and stakeholders stand to benefit.

We note with interest and enthusiasm the emergence of start-up firms pursuing business models for EV charging infrastructure maintenance and support services. While some charging station vendors and service providers currently offer their customers hardware maintenance and upgrade contracts, it seems there is room for third-party maintenance service providers—who might consider all alternative fuel vehicle (AFV) drivers, no matter which brand or model they use, what fuel it uses, or which stations or networks they use—to add significant value by helping to improve the quality and reliability or, and customer satisfaction with, the AFV fueling experience.

Table 10 shows the data type definitions of all the elements of the OA field.

Element Name	Data Type[5, 6, 7, 8]	Description	Comments
OA_SRC: Source	Enum (X, Y, Z)	Device or entity that reported the anomalies.	A single value, naming a party responsible for maintenance. This role is not yet included in this framework. Could be expanded to support error codes from multiple sources, e.g., which are correlated.
OA_AC: Error Codes	Object {String} [1..N]	Array of anomaly codes indicating error or fault condition reported by OA_SRC.	These strings need to be structured following a scheme for categorizing other anomalies. There is currently no standard offering examples or guidance for system-wide anomaly categorization or correlation.
OA_AN: Error counts	Object {Number: integer} [1..N]	Array of number of anomaly code instances reported by OA_SRC (per OA_EC array element).	Error code counts could be stored with array codes in the same N-ary list or array.

Table 10. OA element data types

Foundational Datatypes (CSPR Objects)

It is common system design practice to specify some foundational data types to be used in other field elements. Table 11 shows the data type definitions of these foundational elements, which we might also refer to as “CSPR objects.”

Datatype Name	Data Type[5, 6, 7, 8]	Description	Comments
date_time	Object {JavaScript Date}	“JavaScript Date objects represent a single moment in time in a platform-independent format. Date objects contain a Number that represents milliseconds since 1 January 1970 UTC.”[27]	Defined in ECMA-262 (Section 21.4); conforms to ISO 8601; embraced by IETF (RFC 3339) and W3C; same as Unix epoch time; supported by common methods, e.g., construct, set/get, convert, parse. Example ISO 8601 format rendering (string): 2019-11-14T00:55:31.820Z.[25, 26, 27, 28, 29]
gps_locations	Object {Number:float, Number:float} [1:]	A location, identified by latitude and longitude coordinates.	Values depend on the chosen Spatial Reference System (SRS), e.g., geographic, geocentric, projected, engineering.[14, 15, 16, 17, 18, 19, 20]
pricing_periods	Object {enum (M,Tu,W,Th,F,Sa,Su), time_interval [1..6]} [7]	Basic calendar type, enabling specification of up to six pricing periods each day of the week.	Should be improved to all known tariffs in a more sophisticated calendar, e.g., representing seasons, holidays, 5/2 schedules, etc.
service_type	Object {enum (AC, DC), Number}	Indicates type of service (AC or DC) on a port, and the service port’s maximum rated power.	Number is a float, units are kW; for example: 208 VAC * 30 A = 6.240 kW 240 VAC * 48 A = 11.52 kW 400 VDC * 350 A = 140.0 kW
time_interval	Object {date_time, date_time}	Start and end times of service delivery reported.	Allows representation of any time interval, e.g., 1 hour; 1 week; 70 ms; 2 months, 4 days, 6 hours, 33 seconds; 10 years; etc. Might be expressed per ISO 8601: Time Interval (but see Chapter Four.)[29]
time_quantity	Number	Elapsed time in milliseconds (scalar).	Summation of elapsed time between one or more pairs of end and start date_times. Might be expressed per ISO 8601: Duration (but see Chapter Four.)[29]
tags	Object {String} [1:]	One or more name strings, structured to identify charging service providers, sites, stations, ports, etc., as needed.	Should re-use or align with identifiers already in use, e.g., EVSEID, EMAID (ISO 15118-2, Annex H); OCPI Sections 8.3.1, 8.3.2 (see Table 3.6.2).[30]

Table 11. Foundational CSPR element data types

Using OCPI Protocol Specification Elements in CSPR Interface Data Types

As noted in Chapter Two, the OCPI protocol provides messages for exchanging data about charging system events and service parameters between CNOs and their operational peers, e.g., other CNOs or MSPs. We saw in particular how OCPI could provide a common, system-independent source of charging session start time and end time values.

Similarly, some of the location items defined in OCPI 2.1.1, Sections 8.3.1 and 8.3.2, could be used in the CSPR location tags element. While the underlying CSPR datatype (tags) is a simple JSON string, it would need to be structured in some canonical way to allow different systems to refer to the charging stations and ports precisely and without ambiguity. The OCPI data elements shown in Table 12 provide a rich set of parameters for describing not only the location of charging sites, but other information about site and station accessibility, characteristics, and configuration that could inform the detailed format of the CSPR interface location tag metadata element.[3]

OCPI Data	OCPI 2.2.2 Section	Format (Per the OCPI 2.2.2 Specification)
name	8.3.1	“name”
site_id	8.3.1	
address	8.3.1	“address, city, postal code, state, country”
site_coordinates	8.3.1	“coordinates,” 1 meter precision
parking_type	8.3.1	8.3.1 “parking_type”
public_access		[True / False]
operating_hours	8.3.1	“opening_times”
site_directions	8.3.1	“directions”
evses		List of evse for this site
evse_id	8.3.2	“evse_id”
floor_level	8.3.2	“floor_level”
evse_coordinates	8.3.2	“coordinates”
physical_reference	8.3.2	“physical_reference”
evse_directions	8.3.2	“directions”
parking_restrictions	8.3.2	“parking_restrictions”
evse_capabilities	8.3.2	“capabilities”
evse_status	8.3.2	“status”
evse_status_schedule	8.3.2	“status_schedule”
connectors		List of connectors for this evse
connector_id	8.3.3	“id”
connector_standard	8.3.3	“standard”
connector_format	8.3.3	“format”
connector_power_type	8.3.3	“power_type”
tarriff_ids	8.3.3	“tarrif_ids”

Table 12. OCPI charging site/station data elements

EXAMPLES OF HOW PROTOCOL DATA CAN INFORM CSPR “TOP FIVE” FIELDS

In our survey of protocols in Chapter Two, we noted that OCPP and OCPI provide the most directly relevant and useful data for populating the CSPR field elements. These two protocols are being adopted by an increasing number of charging station vendors and network operators. They are also evolving to meet the needs of the EV charging ecosystem; an example of this is the device model introduced in OCCC v2.0.1, which will continue to evolve. However, until detailed requirements or guidelines for how they should be used are available,[4] some of the data they provide will be less useful than others.

Even so, data currently being exchanged via OCPP and OCPI can directly inform CSPR field elements. We’ll provide some examples, then examine how data from lower-level charging protocols (DIN 70121, ISO 15118, SAE J1772) can also inform elements of the CSPR interface fields.

OCPP v1.6

- StopTransaction message reason codes are particularly useful for reporting charging session interruptions. If their timestamps are accurate (and better, if they are delivered soon after the interruption), they could be especially valuable, e.g., in correlating data from charging stations and EVs on either side of the transaction.

- Status and error code values delivered by StatusNotification messages can be reported directly in elements of the CS, CA, and OA fields.

    - The error codes are most useful—they cover a range of issues, and provide a good start for establishing a comprehensive, systematic way to structure CS_EC values.

    - Some status messages (SuspendedEV, SuspendedEVSE, Unavailable, Faulted) are also directly usable and informative, but their value might vary depending on how timely they are reported.

    - Transitions from charging station states—from available to preparing to charging—could provide data for the CS_SI element, but would need to have accurate time stamps and be delivered timely.

- MeterValue data (drawing on Energy.Active.Export.Register, Energy.Active.Export.Interval, etc.) could be processed and aligned with normal or abnormal end-of-session state transition data, to produce total energy delivered per session, to directly inform the CS_ED element.

OCPP 2.0.1

The latest version of OCPP and the protocol's development roadmap, both described in Chapter Two, deliver powerful, extensible charging infrastructure data collection capabilities that will significantly improve our ability to deliver high-integrity performance reporting.

This is a topic that deserves extended treatment, which we cannot provide here. However, some initial observations on OCPP 2.0.1 will provide a taste of things to come:

- The TransactionEvent message and its values for tracking changes in charging session state provide data that directly informs many of the CS and CA field elements of the CSPR interface.

- The Station Telemetry and Monitoring capability enables operators to diagnose issues in real time. While this entails significant implementation and operational cost, it is a powerful tool for root-cause analysis and statistical sampling, which could serve in refining the CSPR interface by focusing on the most critical issues as the industry evolves.

The adoption of OCPP version 2.0.1 and future versions promises greatly to enhance our ability to deliver the excellent charging experience that EV drivers want, need, and deserve.

OCPI

A virtue of the OCPI protocol is that—like all roaming protocols—it abstracts from the underlying details of device control and management and concentrates on service definition and delivery. By design, OCPI provides a faithful representation of the customer's interaction with charging infrastructure; functions and data that OCPI manages should therefore be especially relevant for several of the CSPR interface elements.

For instance, a charging network needs to be able to report to its EV driving customers the price of charging service at a station managed by a peer ("visited") network, perhaps on a smartphone app. OCPI enables this capability; thus, an OCPI endpoint could be a reliable source of SP element data. It could also provide data for some CS and CA elements, and perhaps other CSPR interface elements as well.

It would be interesting to consider how much additional data processing would be required for an OCPI endpoint to process and provide data for performance reporting, under various system architectures. This kind of exploration would occur in a follow-on CPSR framework implementation effort—see the section on System/Platform Level Considerations.

CSPR INTERFACE: DATA FORMATTING, ENCODING, AND EXCHANGE

There are many ways to represent the fields and elements of the CSPR interface. To facilitate our design and presentation in this report we've defined them using JavaScript Object Notation (JSON), which could be used directly to implement protocol messages or Web APIs.[5, 6, 7, 8] Our JSON design can also support other approaches, e.g., implementation in an XML schema or protocol buffers.

There are many other formatting and encoding methods used in data collection, processing, storage, and retrieval.[9] System implementors consider many factors when deciding which to use for a given purpose, including data volume and anticipated growth; requirements for data processing, storage, and exchange (speed, cost, security, ownership/control); the need for human readability, or not; support in programming languages, operating systems, libraries, and cloud infrastructure; etc.

It's worth noting that the CSPR interface, and the five fields and associated elements as initially specified here, are designed to represent and summarize large data sets. For example, the data a CSP collected to record the charging session initialization times and energy pricing of 7,500 stations with 10,000 charging ports over a month's time could be voluminous, but a database query and response for the summary of that data in CSPR interface fields would only require the exchange of two small JSON messages.

Of course, the raw data from sensors, protocols, etc., would need to be processed (e.g., quantized, aggregated, filtered, synthesized, etc.) to be represented in CSPR interface fields and elements. This leads naturally to a consideration of where this data processing should or could occur and similar system-level questions, which we address in the next section.

SYSTEM/PLATFORM LEVEL CONSIDERATIONS

The CSPR framework comprehends multiple charging systems and components involved in performance reporting, as depicted in the reference architecture section of Chapter Two. The framework, like the CSPR interface, is an abstraction that can be implemented in multiple ways, allowing for flexibility and evolution. While the functionality, connectivity, and performance of the components and subsystems in the framework are not specified in this technical report, some system and platform level requirements should be noted. For example, the end-to-end system data processing and communication performance will have to be adequate for the transformation of situational and operational data (charging protocol data, network and sensor data, third-party data, etc.) into CPSR interface elements. Such high-level requirements would set the parameters for a detailed system design, in which requirements for sub-system computing resources and inter-system communications flows would be specified.[10, 11]

An essential set of system-level requirements will arise from the need to ensure the confidentiality, integrity, and availability (CIA) of CSPR interface data. That is, any implementation of the CSPR framework should embrace information security design principles and commitments from its inception.

One approach would be to introduce performance reporting as a "use case" under the SAE Public Key Infrastructure (PKI) platform.[12] The high-level requirement is for the CSPR interface to be trustworthy, authoritative, and accountable. This might initially or partially be addressed by requirements for system administration and governance, e.g., documentation, auditing, and compliance. Technical means for ensuring system and data CIA, such as methods for establishing digital trust, secure communications, data record hashing and signing, and system and module attestation, could and should be introduced. This would become especially important as more sophisticated functionality involving multiple domains, as shown in Figure 1, is introduced. The need to ensure non-repudiation of contractual commitments for real-time pricing of V2G services would seem to require such technical cybersecurity capabilities in EV charging systems.

Finally, one powerful system-level capability worth pursuing is the ability to correlate data representing charging sessions (or other states or events of interest) that emanate from multiple sources. An obvious example is the correlation of data from an EV and an EVSE pertaining to a fault that occurred during charging. This is represented in Figure 2 as a peer-to-peer interface between OEM and CSP clouds, or via an intermediary data correlation and analysis system (which would scale to multiple OEMs and CSPs). It's a lot easier to depict graphically than to implement in practice. Nevertheless, it seems clear that a mature operational platform would have to support this capability.

The CSPR framework provides a forum for the EV charging ecosystem to develop advanced performance reporting platform features that meet the evolving needs of industry, government, and the EV driving public in a systematic, economically viable way.

ABSTRACT SEARCH EXAMPLES BASED ON THE CSPR INTERFACE

We describe some possible search interactions, showing how CSPR interface elements could be used in queries and responses.

Note that the cardinality of some elements shown here might not match that of their initial definition in this technical report. We've kept the CSPR interface definition simple to facilitate understanding. However, the use of multiple values (tuples, arrays, vectors, etc.) as search input and output is well understood, and it would be a straightforward matter to extend the element definitions to support the search logic desired.

Metadata Search Examples

Search by CSP Name and Time Interval; Minimal Response

This example shows how metadata can be used to report on:

Metadata fields submitted
ET = "Acme Charging Network" [the name of the CSP offering charging services to EV drivers]
TI = "April 2022" [the time interval for which data is desired]

Metadata fields returned
ET, TI = same as submitted [to confirm this dataset represents what was requested]
NR = 17,531 [total number of charging sessions delivered by Acme in April, 2022]
NP = 819 [total number of ports used to deliver those charging sessions]

This query results in a report that there were 17,531 charging sessions delivered on 819 ports on the Acme Charging Network during the month of April, 2022.

Search by Location (Area), and Time Interval; Richer Response

Metadata fields submitted
TI = {1625382000000, 1625382000001} [the first millisecond of July 4, 2021]
GPS = 37.3422600957006, -121.88492560193201 (San Jose, CA, USA)
AR = 15.0 miles

Metadata fields returned
TI, AR = same as above [as query confirmation]
ET= [list of 7 strings, each the name of a CSP operating stations within 15.0 miles of GPS]
GPS = [list of 42 GPS objects, each giving a station location]
LT = [list of 42 strings, each a station location tag]
NP = 211 [total number of ports available for charging at those 42 stations]

Note the time interval metadata value in this example. By requesting data for activity taking place over 1 ms, the query seeks information about the stations and ports available within a given area at a point in time (a snapshot).

This query results in a report of the locations (GPS coordinates) and names (location tags) of the 42 charging stations, with a total of 211 total ports, located within a 15-mile radius of the geographical center of San Jose, California,[13] at the given date and time, along with the names of the seven service providers operating those stations. The LT elements are strings, which would be defined (structured) to include whatever is needed to meet system and user requirements.

To complete the example, we provide some mock query responses:
ET = {"Acme Charging Network"; "BetterChargeNow"; …} a list of seven Entity Tags (strings)
GPS = {37.3195909646492, -121.86327455106272; 37.33635858657506, -121.88599851279142; …}
a list of 42 GPS coordinates (pairs of Numbers)
LT = {"Acme #14: Civic Center Parking Garage, 171 W Hedding St, San Jose, CA 95110; Second Level";
"BetterCharge CS133: Municipal Stadium, 588E E Alma Ave, San Jose, CA 95112; Outdoor Lot"; …}
a list of 42 Location Tags (strings)[2]

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[2] Note that the location tags in these examples are only indicative, and do not conform to OCPI as suggested in Table 12.

Service Availability (SA) Search Examples

Search by CSP Name and Time Interval

Metadata elements submitted as input:
ET = “Acme Charging Network”
TI = “April 2022”

Metadata elements returned:
ET, TI = same as submitted [to confirm this dataset represents what was requested]
NR = 17,531 [total number of charging sessions delivered by Acme in April, 2022]
NPP = 819 [total number of ports used to deliver those charging sessions]

Service Availability elements returned:
SA_TT: 259199999 (number of milliseconds, 2022-04-01 00:00.000 to 2022-04-30 23:59.999)[3]
SA_OT: 2527199999 (the value in milliseconds representing 97.5% uptime)
SA+ET: 0 (station was supposed to be available for public charging 24/7)

This example query response reports that Acme Charging Network operated its network in April, 2022, with 97.5% availability, 24/7—a pretty good month for charging station reliability.

Search by Station Location and Time Interval

Metadata elements submitted as input:
TI = “2022-07-04”
LT = “BC-DCFC133: Municipal Stadium, 588E E Alma Ave, San Jose, CA 95112; Outdoor Lot”

Metadata elements returned:
TI, LT = same as submitted [to confirm this dataset represents what was requested]
ET = {“BetterCharge Now”}
NR = 0 [total number of charging sessions delivered by BC-DCFC133 during those 24 hours]
NP = 2 [total number of ports available on BC-DC133]

Service Availability elements returned:
SA_TT: 86400 (number of milliseconds in 24 hours)
SA_OT: 2,318 (the value in milliseconds representing 4.15% uptime)
SA_ET: 28,800 (station not intended to be available for public charging, 8 of 24 hours that day)

This example query response reports that charging station BC-DCFC133 was only operational for 4.15% of the 16 hours it was meant to be available for public charging. Apparently, something wasn’t working right that day.

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[3] Thirty days minus 1 ms, according to https://codechi.com/dev-tools/date-to-millisecond-calculators/. Provided for illustration only; might not be the value given by an operational system.

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Chapter Four: Results and Recommendations

RESULTS

This report provides stakeholders across the EV charging ecosystem—drivers, OEMs, service providers, fleet operators, grant administrators, regulators, researchers, and others—with guidance for developing best practices and an operational system for CSPR.

It was developed by technical experts from industry-leading companies and laboratories, who lent their extensive first-hand knowledge of EV charging system standards, product and system development, and large-scale operations to the effort. This Technical Working Group was given its direction and scope by the SAE SMS Strategic Advisory Council, who identified the pressing need for this work in the context of accelerating market transformation, growing customer expectations, and unprecedented government and public policy incentives for the adoption of alternative fuel vehicles. This context is presented and explored in Chapter One.

Chapter Two introduced a technical framework for CSPR, based on a reference architecture that depicts the key components, subsystems, and interconnections from which standardized performance data could be (and to some extent, already is) derived. The CSPR framework leverages the powerful information-system concept of abstraction to posit an interface that would represent salient performance characteristics of the entire charging system. This CPSR interface is formally defined Chapter Three.

In order to determine what kind of performance reporting might already be possible, Chapter Two includes a survey of communication protocols currently used in charging systems. We identify some data elements that could, directly or indirectly (i.e., without or with further processing), inform the CSPR interface. We selected and analyzed these data elements according to their relevance to the “top five” EV charging issues that the TWG, drawing on the experience of EV drivers and researchers, believe are currently the most critical in priority.

Chapter Three provides a formal specification for the CSPR interface, an abstract data type defining six fields—one for each of the “top five” issues, one for metadata—and field elements with the parameters used to request and retrieve charging system performance reports. While the CSPR interface is precisely defined, it is not set in stone—quite the opposite. It could easily be modified, for instance to include more fields For example, there might be a need to report seven or 11 or 23 performance characteristics. Some element formats might need to be adjusted to facilitate some data collection and processing patterns that we have not anticipated. Even so, the initial version of the CPSR interface is not only at the right kind and level of abstraction, but it is immediately useful. Our JSON design could be implemented with a modest investment in prototyping and proof-of-concept, to demonstrate the feasibility of CSPR on the most pressing issues EV drivers are currently facing on every network in operation.

Our results can be summarized as follows:

- An *overview* of the current state of CSPR and factors driving the need for *improvement* in this area.
- A *framework* for conceptualizing and specifying system interactions that would support CSPR.
- A directly operable, extensible information system *interface* that structures and facilitates the processing of charging system performance data.
- An *analysis and assessment* of common, open standards-based charging system protocols and the value of their data elements for CSPR.

RECOMMENDATIONS

We suggest/recommend that:

- The notion of a/the charging session and its sequence diagram or process flow be defined and agreed upon across the ecosystem. They should be user-centric, not device- or system-centric, since we're trying to represent the EV driver's experience.

- The industry establish or designate an official naming authority that will manage the assignment of critical identifiers, like CSP and OEM and EVSE vendor, etc. We suggest that the (single) policy authority/management authority of the industry PKI might be a logical entity to fill this role.

- CPS and OEMs try to validate the CSPR interface. That is, determine how well the defined formats, parameters, etc., work as interfaces to the database(s) they currently populate and query to assess product/system performance, reliability, etc. Would you modify some fields or elements? Add some, delete some, etc.?

- CPS and OEMs evaluate our suggestion that roaming protocols, specifically OCPI, represent/s the best or only system-wide (other; i.e., charging protocol-independent) representation of the EV driver's interaction with the charging infrastructure.

  - Does or should OCPI subsume or re-present data from OCPP? Or should some data pertaining to the charging session come from OCPP? e.g., the v2.x Device Model?

- The "system of record" be defined and designated for every data element or steam that is used for performance reporting.

- The PKI operating entity (PA/MA) determine whether CSPR (generally or specifically) is a good fit with PKI and, if so, what is needed for cryptographic assurance of performance reporting data integrity, etc.?

- CSPs and OEM research the device model capabilities of OCPP v2.0.1, join the new OCA effort to establish guidelines or requirements for using the device model in systematic ways, etc.

- CSPs and OEMs help OCA establish a roadmap for OCPP 2.0.1 adoption, deprecation of OCPP v1.6, expected calendar for new versions (one minor version a year? Two? One every 2 years? What are the criteria for minor vs. major version? etc.).

- CSPs and OEMs engage SSOs an de facto industry standard WGs on how to add elements for performance reporting to their protocols (e.g., SAE J1772, ISO 15118, OCPP, OCPI, CHAdeMO 3.x, etc.) in future minor revisions.

- Any charging system protocol standard development effort consider what is needed to support performance reporting, how data from their protocols adds to (and doesn't duplicate) data from other sources, etc. (bottom-up approach).

- SAE SMS convene other industry stakeholders to discuss and if possible, come to agreement on what needs to happen to drive performance and reliability requirements (top-down approach).

- SAE SMS continue to engage with similar efforts, e.g., Atlas Public Policy's Charging Use Specification Project, etc.

- Formal, precise definitions and descriptions for measuring uptime, failure to charge, etc., need to be consensually developed and accepted.

- SAE SMS continue their efforts to align industry efforts with policy initiatives.