Protocol Interoperability for Intelligent Transportation Systems

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Abstract: Transportation is an essential part of daily life. To ensure optimal transportation of people and goods, all stakeholders, including traffic participants, infrastructure providers, and service providers, must be interconnected. This interconnectivity enables efficient traffic management, energy and noise reduction, and safe driving. However, integrating different systems via various communication technologies and protocols can pose challenges to ensuring information quality, reliability, security, and privacy. As communication becomes a more critical safety factor for connected and automated driving, and more systems are involved in communication, ensuring data quality becomes increasingly crucial. This includes data availability, range, precision, privacy, and security. This paper presents an evaluation mechanism for assessing the quality of standardized protocols in terms of interoperability. It can be concluded that, although many protocols exist in the field of intelligent transportation systems, they transport similar information but differ in details that may impact the applications working with that information.

1 INTRODUCTION

In the field of Intelligent Transportation Systems (ITS), separate ecosystems have been established in recent decades. These ecosystem includes in-vehicle, traffic infrastructure, service-oriented, and direct communication systems. As current efforts to shape future mobility include Cooperative, Connected and Automated Mobility (CCAM), these once distinct ecosystems must now interact. This interaction is essential to the creation of a safe, eco-friendly, and efficient transportation system. Users are more likely to adopt new multimodal mobility options if their mobility experience does not deteriorate. Therefore, the acceptance of these options is determined by these three objectives. Each ecosystem has its own communication and application needs, which result in the creation of domain-specific specifications for data representation, application and communication protocols, and communication technologies. Interoperability is crucial for the development of ITS and future mobility.

Protocols are used in various scenarios and fields and can serve general or specific purposes. They can be categorized based on their formal and informal specifications. The protocol specification combines different components, starting with the specification of the protocol's context. Then, the protocol description is specified, combining messaging and behavior. Finally, data values are defined. For example, the Internet Protocol (IP) is a versatile protocol used in numerous contexts, serving as a network protocol for the Internet. In contrast, the Decentralized Environmental Notification Message (DENM) is an application layer protocol created for a specific purpose and environment, specifically for use in Cooperative Intelligent Transportation Systems (C-ITS).

In this diverse environment, it is important to establish clear guidelines for transmitting data, including when and what data should be transmitted. Application developers can no longer rely on closed ecosystems, such as those found in-vehicle or in traffic infrastructure. Instead, they must be able to adapt to changing environments, unfamiliar data sources, and fluid communication environments. To do so, they must establish mechanisms for distinguishing between different protocols, data representations, and communication behaviors. It is important to note that

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not all protocols may be adapted and common protocols and data formats may not be used. We have developed an evaluation scheme to help application implementers to identify possible interoperability issues. This will enable developers to focus their attention on those issues. This is just the first step. A complete evaluation involves assessing the connection between specifications based on references, comparing formal data specifications automatically, evaluating the data itself, and assessing the ecosystems and architectures for applications that use the specifications. These additional steps are not included in this paper.

The paper is structured as follows: Section 2 details related work, Section 3 outlines the classification approach, Section 4 presents the findings and Section 5 discusses these results. Finally, Section 6 presents the conclusion and provides an outlook for future work.

2 RELATED WORK

The number of ITS standards is constantly changing. Publishers release new standards, remove outdated specifications, and revise current ones. Standards organizations monitor these changes through their in-house and external mailing lists and websites. There are publications, such as book chapters (e.g., (Williams, 2008), (Ernst, 2021)), and papers that summarize the activities related to standards.

In their 2009 publication (Festag and Hess, 2009), Festag and Hess provide an account of the early standardization processes and objectives in Europe. The European ITS Station Reference Architecture is detailed in (Festag, 2014), (Kosch et al., 2009), and (Sousa et al., 2017) with specific attention to the cooperative ITS (C-ITS) segment for direct communication. Various publications outline the current status of ITS standardization and deployment in different countries or regions. One example is Macioszek's study (Macioszek, 2014), which focuses on the situation in Poland. (Feng et al., 2017) discuss standardization in China, while (Lim, 2012) and (Sugimoto, 1999) present plans for ITS in Korea and Japan, respectively. (Padmadas et al., 2010) explain the deployment of ITS in developing countries using the example of license plate recognition and Djalalov (Djalalov, 2013) discusses the role of standardization in general. (Lonc and Cincilla, 2016) and (Hamida et al., 2015) provide detailed information on security aspects related to the architecture. Identity and credential management requirements are detailed in (Khodaei and Papadimitratos, 2015). The distribution of data and knowledge systems is examined in (Přibyl et al., 2021), and ITS architecture requirements for information distribution based on application viewpoints are available in (Ren et al., 2001). Research projects like sim^{TD} (Stübing et al., 2010) and C-MOBilE (Lu et al., 2018) also address these topics. Standardization issues related to communication are covered in (Nsonga and Ustun, 2016) (EV IEC 61850 and WAVE), as well as in (Zeadally et al., 2020) (5G NR V2X and IEEE 802.11bd). Special attention should be paid to functional safety in ITS interoperability, as highlighted in (Mariani et al., 2021). Standardization organizations provide overviews of their specifications (CEN, 2024), (ETSI, 2024), (ISO, 2024). The International Telecommunication Union (ITU) offers a synopsis of standardization documents from different SDOs (ITU, 2024), allowing for easy searching of documents from 16 organizations, with a database of 1,265 files. Interoperability is discussed in other ecosystems using two approaches: defining a common protocol/mapping or introducing a middleware. The former approach has been explored in several studies ((Park et al., 2009), (Cruz-S'nchez et al., 2012), (Yacchirema et al., 2017), (Derhamy et al., 2017), and (Bromberg et al., 2011)), while the latter has been investigated in other works ((Nakazawa et al., 2006), (Cavalieri, 2021), and (Bouloukakis et al., 2019)). Both approaches have their challenges. The former requires a consensus among all stakeholders, while the latter would require modifications to various areas, which would not be feasible given the current framework conditions in both vehicles and traffic infrastructure.

Although there is literature that offers a general overview of the field, none has provided insights into interoperability specific to ITS. To the best of our knowledge, specific research has been conducted on standards interoperability in the various ITS ecosystems.

3 APPROACH

The evaluation approach is based on classifiable criteria. The following section outlines these criteria, along with relevant calculations.

The criteria are divided into five groups: meta-information, protocol category, communication participants, protocol description, and protocol testing. The *meta-information* describes the formal specifications, while the *protocol category* specifies the type and purpose of the protocol. The criteria for *communication participants* outline the systems and entities involved in communication and categorize the communication itself. The *protocol description* outlines the protocol's execution environment, intended use, and context. *Protocol testing* incorporates mechanisms to assess the protocol's implementation.

Figure 1 shows the five main categories of classification criteria: *meta information*, *protocol category*, *communication participants*, *protocol description*, and *protocol testing*. These categories answer the questions: what are the formal criteria, what is the context/purpose of the protocol, who is communicating with whom, how is the protocol described, and how can the protocol be tested and validated?

Figure 1 displays a total of 39 criteria. The criteria are organized into separate vectors to ensure objectivity bias and provide a clear picture. Sub-vectors are evaluated as a group. Values that are not comparable or consist of text are divided into a more detailed set of parameters to facilitate relative comparison. For values that already consist of multiple values, a sub-vector is created.

The following list provides guidelines for comparing standards, focusing on the most important criteria.

- p_{is+ik}. The protocol issuer is identified solely by name, making it difficult to compare. To facilitate comparison, a vector of determining factors is used. The vector includes the following fields in the specified order: public/private, profit/non-profit, international, African-based, North American-based, South American-based, Asia-Pacific-based, European-based, national, national standardization body, ITS-domain-specific topics, and communication-specific topics.
- p_{ve}. The protocol version is an important indicator of whether the same version of the standard is being used. It should not be assumed that the latest version of the standard is always in use, as legacy systems may still use older versions. Additionally, the specification can be influenced by the options and profiles of the standard. The version may consist of a number, text, or a combination of both.
- p_{la}. Language can have an impact on the ability of individuals to work with a specification. While many international specifications are written in English, some national and regional specifications are written in the native language of the country or region. This can create challenges for implementing an interoperable solution if the specification is not easily accessible due to language barriers. This criterion is not directly related to interoperability in a strict sense but rather to the ability of the implementer to understand and implement the specification. Misunderstandings could potentially lead to interoperability issues.
- p_{sf}. The comparability of a specification may be affected by whether it belongs to a standard family or not. In some cases, this may result in an incomplete specification that requires other parts of the specification family to be interpreted. Therefore, it is important to thoroughly investigate the family membership. However, a specification may still be complete even if it is of a family. It is important to consider different options and combinations. The following example pertains to two standards. If both standards belong to the same family, they are expected to have the same values. If both standards are from different families or not from any standard family, the values should be different, but the properties may be the same. However, if only one standard is from that family and the other is not, different values are expected. Therefore, it is necessary to extend this value with the name of the standard being compared. In this manner, different families would produce unique results, and the lack of families would also produce distinct outcomes.
- p_{gv}. The validity of a specification is directly related to the geographical area and the available information and how its interpretation. While other intentions may remain the same, the interpretation may vary.
- p_{mr}. The presence of necessary references is comparable to p_{sf}. Including references implies that the specification is not self-contained and needs additional information for a full assessment and comparison. If neither specification contains normative references, no further investigation is necessary. If one or both documents cite normative references, it indicates a need for a closer examination of the values presented.
- p_{fs}. A formal specification, such as Specification and Description Language (SDL), Message Sequence Charts (MSC), or Unified Modeling Language (UML), must be used to describe a protocol precisely and without ambiguity. While a written protocol can be open to interpretation, formal languages leave no room for misunderstandings. However, there may be some flexibility in the specification of these languages for describing the same protocol.
- cat. The protocol category indicates the protocol type and its potential applications. The position within the hierarchy demonstrates the relative relationship between the protocols. The greater the differences in values, the further apart the category and intended protocols are.
- c_{ps+pr}. Many protocols are designed for specific

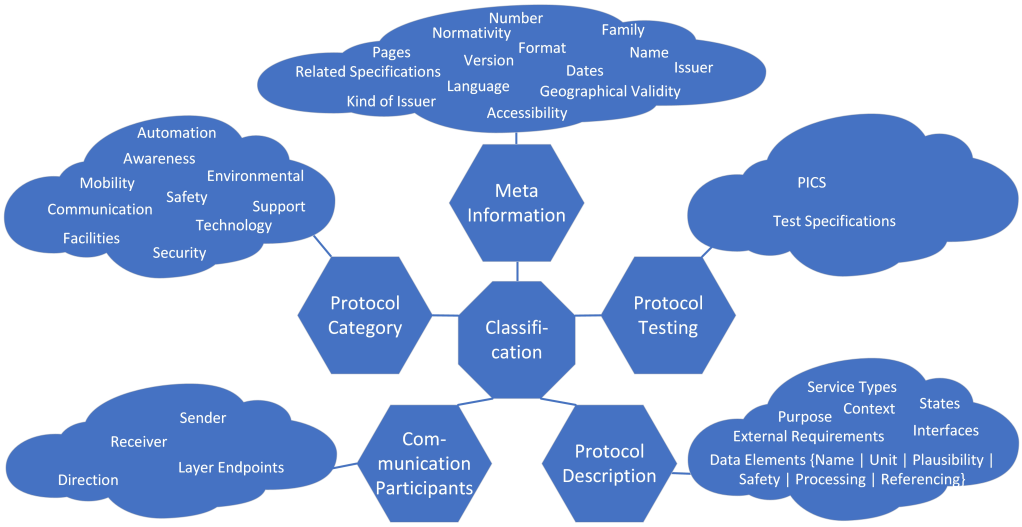

Figure 1: Overview about the classification criteria.

use cases. They define information flow as an exchange between two designated systems. For instance, communication between a Traffic Management Center (TMC) and a Traffic Light Controller (TLC). On the other hand, some protocols serve a general purpose. Internet Protocol (IP) is a protocol for any scenario where information is communicated between independent systems. Communication can be affected by the abilities of the source and destination when combined. In the case of ITS, multiple layers can be identified (refer to (ETSI, 2010a)). The sender and receiver may be situated in the same or different layers. The values indicate the layer or layers where communication is intended to take place.

- c_{en+di}. The endpoints define the relationship between the transmitter and receiver in a transmission, indicating the linkage and communication direction. This is important because some protocols operate unidirectionally, while others require two-way communication. Understanding both values provides insight into the protocol designer's intentions.
- d_{co+pu}. Sometimes protocols are specified without providing context. However, including the necessary information can aid in interpretation. Comparing context and purpose is interesting and indicates that more information is available.
- d_{is}. Interfaces can be included in a protocol specification to specify input and output information, primarily input. This information can come from data flow, management, or security entities. The presence of these interfaces provides insight into the intended environment for the protocol.
- d_{re}. External requirements can provide more information to assess the purpose and framework conditions of the protocol.
- d_{ps}. When comparing two protocols, aside from the actual data, the behavior of the protocols is relevant, particularly when anticipating information transfer between two distinct protocols.
- d_{pt}. If a protocol provides information through push or pull, it can greatly affect interoperability. If one protocol requires data to be pushed, but the other only supplies data upon being pulled, then interoperability is impossible.
- d_{dn}. Comparing data elements can be challenging when unclear descriptions are used. Therefore, a clear naming pattern is crucial for comparison. For instance, if a value is referred to as 'speed' rather than just 's', it becomes easier to understand. It is essential to avoid ambiguous technical terms that hinder comprehension.
- d_{du}. The importance of clearly specifying the unit of data elements cannot be overstated. Whenever possible, the name of the unit should be included in the element name, such as 'speed_metersPerSecond'. If the unit is not already specified, the specification should provide clear clarification, including information about the referencing system, such as elevation and altitude.
- d_{dp}. Plausibility value should be provided for values that cannot be precisely determined. For example, a measurement error may be introduced when obtaining a position from a Global Navigation Satellite System (GNSS) source. It is important to communicate this information alongside

the data so that the recipient can take it into account when interpreting the data.

- d_{ds}. The criteria for determining the suitability of a data element for functional safety are crucial for achieving interoperability. Different protocols exhibit different methods in this regard.
- d_{do}. To assess data, the type of data provided and its processing are critical factors.
- d_{dr}. The reuse of data elements from another specification should be considered, as it is connected to the incompleteness of the specification.
- t_{p+pd}. The Protocol Implementation Conformance Statement (PICS) enumerates the components of the specification. It clarifies which parts are required, optional, or conditional, and which are included in the context of a particular implementation.
- t_{s+sd}. The test specifications provide insight into the relevant components and the minimum functionality that can be expected from any implementation.

To assess the SDO, we have established twelve criteria presented in Table 1. Each criterion has a binary value, with only two possible outcomes: zero or one.

Table 1: Protocol issuer classification.

Column	Explanation
1	SDO is either private (0) or public (1) founded.
2	SDO is either a non-profit (0) or a profit (1) organization.
3	SDO is an international organization (1) or not (0).
4	SDO is responsible for Africa (1) or not (0).
5	SDO is responsible for North America (1) or not (0).
6	SDO is responsible for South America (1) or not (0).
7	SDO is responsible for Asia-Pacific (1) or not (0).
8	SDO is responsible for Europa (1) or not (0).
9	SDO is responsible on a national level (1) or not (0).
10	SDO is a national standardization body (1) or not (0).
11	SDO specifies ITS-domain-specific topics (1) or not (0).
12	SDO specifies communication-specific topics (1) or not (0).

To explain table 1, we provide an example below. The value for the European Telecommunications Standards Institute (ETSI) is 100 000 010 011. ETSI is a non-profit (second digit) European standardization organization authorized by the European Commission for C-ITS (EU, 2009). It creates specifications for the European Union (third digit) ans is publicly-funded (first digit). Therefore, digits four to seven are zero and digit eight is marked as one. ETSI is not a national SDO and is only indirectly responsible for national specifications. Certain ETSI documents are transferred to the national SDO via CENELEC. Therefore, digits nine and ten are set to zero. ETSI is responsible for communication protocols specific to intelligent transportation systems, as well as general communication protocols and application protocols specific to intelligent transportation systems (digits 11 and 12 set to one).

4 RESULTS

Evaluations based on the given criteria and preparation have been conducted. Table 2 shows the results of selecting four different documents to visualize the approach: ETSI DENM (ETSI, 2010b), International Organization for Standardization (ISO) Signal Request Message (SRM) (CEN, 2019), SAE International (SAE, formerly Society of Automotive Engineers) Radio Technical Commission for Maritime Services Message (RTCM) (SAE, 2016), and German Federal Highway Research Institute (BASt) Technical guidelines for outstations (TLS) (Bundesanstalt für Straßenwesen Bergisch Gladbach, 2013). This excerpt discusses the challenges of using the classification. The specifications for DENM and TLS are stand-alone. The remaining two cases are unique, as they relate to a specific section of the specification. The specification (SAE, 2016) is a collection of several specifications, and the RTCM message is one of those defined within it. All of these messages share the same data header and frame format. The purpose of the SRM is twofold: to define the application protocols, including six of SAE's 15 protocols (four of which are extended), and to describe the requirements and use cases for those six protocols. The geographic region can generally be determined by the jurisdiction of the issuing institution.

The formal specification is provided in three of the four specifications, with an expanded description of the protocol's behavior in three of the four instances. The DENM protocol is the only protocol designed for all communication endpoints. RTCM and DENM are unidirectional. TLS, on the other hand, is bidirectional (request-response). The directionality of SRM is unclear. The message is transmitted without an expected SRM message in return and instead requires a Signal Status Message (SSM). The specifications may not always consider external requirements (1/4) and context (2/4), but they always include the purpose to varying degrees of detail. The clarity of descriptions for data elements and units may not always be consistent, with the TLS specification using a distinct descriptive technique compared to the other three. Finally, two of the specifications are self-contained. One includes specific references, while the other uses non-specific references.

Table 2 presents values that are primarily coded for simplified automated comparison. These values are binary-coded as a bitfield to allow for combinations. The values in the table are defined upon introduction, with few exceptions. The category (*cat*) includes 20 distinct values. This criterion uses four different identifiers. These include 8 for application environmental, 16 for application mobility, 36 for application awareness (4) and application safety (32), and 2088 for application awareness (4) and application mobility (16) and ITS-related facility communication (2048). The values for the sender and receiver (c_{ps+pr}) are categorized as back end (1), infrastructure (2), pedestrian (4), vehicle (8), and other (16). Table 2 uses the following abbreviations: bac (backend), bidi (bidirectional), ex (external), inf (infrastructure), ref (references), spec (specific), uni (unidirectional), and veh (vehicle).

Generative AI systems such as OpenAI ChatGPT, Mircosoft Copilot, and Google Gemini can be utilized to expedite the process. They can provide an overview based on the given criteria for preliminary assessment. Table 3 illustrates the combined feedback provided by the three AI systems for comparing the Cooperative Awareness Message (CAM) (ETSI, 2019) specification of ETSI and the Basic Safety Message (BSM) (SAE, 2016) specification of SAE. The query ('Compare the specifications of ETSI CAM and SAE BSM based on the following criteria and show the result in a table. The criteria are protocol issuer, protocol version, protocol language, belongs to a standard family, geographical area the protocol is valid, contains normative references, includes formal specification, defines specific sender and receiver, defines communication endpoints, provides context and purpose, includes interface description includes requirements, is a stateful or stateless protocol, push or pulls information, conforms to data naming convention, includes plausibility values for data, includes information for functional safety, resues data types, includes PICS, includes test specification.') was asked three times for every AI system.

5 DISCUSSION

Table 2 provides guidance for developers on transferring information between specifications. For instance, consider DENM information and TLS telegrams. These specifications differ significantly in their approach and fall into separate categories (*cat*) of ITS protocols, namely application safety (DENM) and transport communication (TLS). Additionally, they are written in different languages (p_{la}). This is not a technical interoperability issue, but rather a human one. To understand the details of a specification and implement data interoperability correctly, developers must grasp its meaning.

It is worth noting that DENM is a stateless protocol, while TLS is stateful (d_{ps}). The impact of this difference depends on the specific situation in which both protocols are used. If only data is being transferred from one protocol to another, the state may not be relevant. However, if an application is waiting to receive data via TLS and DENM is not providing this data, it could cause the application to stall until the data arrives. If an application includes both protocols, it may face the challenge of information asymmetry, where information is requestable via TLS but not via DENM. This could lead to situations where applications do not possess all the information necessary to evaluate a situation.

TLS does not have any formal specifications, but it includes some behavioral aspects (p_{fs}) related to the protocol states. The data definitions differ between TLS and DENM's specifications. TLS uses only numbered fields with explanations for data element naming (d_{dn}), while DENM's specification depends on other data definition specifications (ETSI Common Data Dictionary (ETSI, 2023)). TLS's data definition is complete in this regard (d_{ds}). Only certain parts of the information can be transmitted due to the significant differences in the data elements. Furthermore, while both TLS and DENM contain information about data plausibility, they are not compatible upon closer inspection. DENM has extensive test specifications available, whereas TLS does not (t_{p+pd}).

Table 3 presents the combined results of three AI systems: OpenAI ChatGPT, Microsoft Copilot, and Google Gemini of ETSI CAM and SAE BSM. None of the systems produced a comprehensive result, and they even contradicted each other on aspects such as geographical area and testing capabilities. Often, the correct specification, EN 302 637-2 for CAM, was not identified, and instead, DENM EN 302 637-3 was mentioned. At times, even in versions such as 2.2.1, which does not exist yet. The J2945-1A specification is mentioned regularly for SAE instead of J2735, which is the test specification for J2735. Prior knowledge of the protocols is necessary to understand and process the results at the current development state. It is important to note that the results may vary when two equal requests are made to the same AI system.

The criteria can be applied to a wide range of situations. If a simple comparison of communication is required, only certain values should be used, such as the data values d_{dn}, d_{do}, and d_{du}, the states d_{ps}, and the communications paradigm d_{pt}. The communication and protocol categories criteria can be used to establish primary compatibility. When conducting

Table 2: Classification example.

Criteria	DENM	SRM ISO	RTCM SAE	TLS
p_{is+ik}	100 000 010 011	010 000 000 111	011 010 000 011	100 000 001 011
p_{ve}	Version 1.3.1	2019	Jul 2020	2012
p_{la}	English	English	English	German
p_{sf}	4 (alone)	2 (part)	2	4
p_{gv}	2 (Europe)	2 (America, Japan, Europe)	0	4 (National)
p_{mr}	1 (8 ref)	1 (15 ref)	1 (15 ref)	1 (25 ref)
p_{fs}	1 + behavior	1 + behavior	1	0 + behavior
cat	36	16	8	2068
c_{ps+pr}	15 + 15	2 (inf) + 8 (veh)	2 + 12 (mainly)	1 (bac) + 2
c_{en}	63 (all)	8 (f-p)	2 (c-p)	1 (c-f)
c_{di}	1 (uni)	1 or 2 (bidi, with SSM)	1	2
d_{co}	2 (no)	1 (yes)	2	1
d_{pu}	1 (yes)	1	1 (short)	1
d_{is}	1 (yes)	2 (no)	2	2
d_{re}	2 (no)	1 (yes) some extend	2	2
d_{ps}	2 (stateless)	2 (1 with SSM)	2	1 (stateful)
d_{pt}	1 (push)	1	1	4 (both)
d_{dn}	1 (self)	4 (partly)	1	16 (not applicable)
d_{du}	1 (yes, ex)	8 (partly)	1 (yes)	8
d_{dp}	4 (some)	4	4	4
d_{ds}	4 (some)	2 (no)	2	2
d_{do}	8 (undefined)	8	8	8
d_{dr}	1 (yes, spec)	2 (yes, non-spec)	0 (no)	0
t_{p+pd}	2 (yes, ex) + (ETSI, 2020a)	2 (yes, ex) + (ETSI, 2021a)	0 (not applicable)	2 (no)
t_{s+sd}	2 (yes, ex) + (ETSI, 2020b) and (ETSI, 2020c)	2 (yes, ex) + (ETSI, 2021b) and (ETSI, 2021c)	2 (no)	1 (yes, part)

Table 3: Comparison of ETSI CAM and SAE BSM.

Criteria	ETSI CAM (EN 302 637-2)	SAE BSM (J2735)
Protocol Issuer	ETSI	SAE International
Protocol Version	EN 302 637-2 V1.4.1 (2019)	J2735 (July 2020)
Protocol Language	English	English
Belongs to a Standard Family	ETSI ITS	V2X communications
Geographical Area Validity	European Union	Primarily North America
Contains Normative References	Yes, lists multiple ISO, ETSI, and IEEE standards	Yes, lists multiple SAE and IEEE standards
Includes Formal Specification	Yes, uses ASN.1 for data encoding and message structure	Yes, uses ASN.1 for data encoding and message structure
Defines Specific Sender and Receiver	Yes	Yes, sender is an OBSE and receiver is any DSRC station
Defines Communication Endpoints	Yes, uses DSRC ITS-G5 communication channels	Yes, uses DSRC ITS-G5 communication channels
Provides Context and Purpose	Cooperative awareness	Safety communications
Includes Interface Description	Yes, specifies message structure and encoding rules	Yes, specifies message structure and encoding rules
Includes requirements	Yes, specifies requirements for message content and transmission	Yes, specifies requirements for message content and transmission
Stateful or Stateless protocol	Stateless	Stateless
Push or Pulls Information	Push (broadcast-based)	Push
Conforms to Data Naming Convention	Yes, uses defined ASN.1 data types and names	Yes, uses defined ASN.1 data types and names
Includes Plausibility Values for Data	Not specified	Not specified
Includes Information for Functional Safety	Not specified	Not specified
Reuses Data Types	Yes	Yes
Includes PICS	Yes	Yes
Includes Test Specification	Yes	Yes

protocol testing, the criteria can be used to determine the defined test procedures and their compatibility.

The findings offer guidance to developers and system architects, providing insight into critical fields for the system, application, or use case.

6 CONCLUSION AND FUTURE WORK

We proposed a mechanism for evaluating the informal part of ITS specifications. The proposed categories provide a comprehensive summary of the specifications and allow for comparison between various specifications. This knowledge enables the identification of potential interoperability issues before finalizing system or application design and implementation. Although these measures do not replace integration and interoperability testing, they provide a means to make design choices, reducing problems early on in the creation process. The defined categories can be customized to serve specific objectives, either independently or as a subset.

Weights can be added to values to emphasize specific needs. This flexible approach allows for adaptation to varied settings and requirements. However, precise interpretation of specifications is vital, especially due to imprecise terminology that can lead to identical concepts being described differently. Generative AI systems can provide an initial overview, but they are currently unreliable in extracting the required information from specifications. Additionally, they cannot access specifications that are behind a paywall. Even though the TLS (Bundesanstalt für Straßenwesen Bergisch Gladbach, 2013) specification is freely available, none of the three systems were able to access it. Therefore, a specialized evaluation system should be developed to meet the unique needs of the evaluation process.

The next step is to fully automate the analysis of formal specification sections, including comparing data definitions in ASN.1 or UML. The purpose of this analysis is to identify corresponding or seemingly corresponding data fields and address the issue of word ambiguity, such as the difference between speed and velocity or elevation and altitude. Subsequently, we will evaluate the linkage between ecosystems, architectures, and protocols.

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