White Paper on the description of lane layouts

CAR 2 CAR Communication Consortium

About the C2C-CC

Enhancing road safety and traffic efficiency by means of Cooperative Intelligent Transport Systems and Services (C-ITS) is the dedicated goal of the CAR 2 CAR Communication Consortium. The industrial driven, non-commercial association was founded in 2002 by vehicle manufacturers affiliated with the idea of cooperative road traffic based on Vehicle-to-Vehicle Communications (V2V) and supported by Vehicle-to-Infrastructure Communications (V2I). The Consortium members represent worldwide major vehicle manufactures, equipment suppliers and research organisations.

Over the years, the CAR 2 CAR Communication Consortium has evolved to be one of the key players in preparing the initial deployment of C-ITS in Europe and the subsequent innovation phases. CAR 2 CAR members focus on wireless V2V communication applications based on ITS-G5 and concentrate all efforts on creating standards to ensure the interoperability of cooperative systems, spanning all vehicle classes across borders and brands. As a key contributor, the CAR 2 CAR Communication Consortium and its members work in close cooperation with the European and international standardisation organisations.

Disclaimer

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Table 1: Document information

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Table 2: Changes since last release

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Abbreviations

Commonly used abbreviations are defined in the C2C-CC Glossary, see [RD-3]. Additionally used abbreviations are defined in the following list.

Abbreviation	Description
OSM	OpenStreetMap
ADAS	Advanced Driver Assistance Systems

1 Introduction

This White Paper summarizes the results of the WorkItem 'Description of Lane Layout'. The WorkItem was initiated due to the need of harmonized rules for the counting of lanes when a vehicle drives on a road (i.e., on which lanes is the vehicle currently driving or on which lane is an event located). This information can be useful for various applications, like:

- advanced ACC functions to find out if a vehicle is driving on the same lane or not (especially on curvy roads)
- advanced warning function to show in an HMI the blocked lane and other, free lanes.
- Automated / autonomous vehicles. The he information about blocked and alternative lanes can also be used by them to be get more detailed information about a situation and derive appropriate measure how to deal with and pass the situation.

The assumption is that explicit information on lane level positioning is needed in addition to the geographic location of the vehicle, since the minimal required accuracy of the latter is yet too low (see RS_BSP_209 in [RD-23]) to allow for lane level positioning in all cases. Adding lane information and the road layout to DENMs was the objective of the WorkItem 'Road Configuration information for inclusion in DENMs', developed in parallel to this work item. The results of both WorkItems are aligned, they used the same conferences calls to discuss the issues.

While this seems to be trivial on a first look, a deeper look into some scenarios had identified the room for different interpretations and approaches for counting lanes (see clause 1.2). To contribute for the objectives above, a common understanding between all participants is necessary – not just vehicles also road operators, as they can generate DENMs as well. All have to use and follow a single set of rules and guidelines. Otherwise, if a C-ITS-S *A* (from operator A) issues a DENM about an event on a certain lane, C-ITS-S *B* (from operator B) may misinterpret the lane and assumes the event to be on another lane as provided by the DENM-issuer. The objective of this WorkItem was to find such rules and guidelines, by considering existing work (see clause 2) and investigating a set of different scenarios (see clause 3). The evaluation led to the agreed guidelines (see clause 4) and some open points and future work, which was beyond the scope of this WorkItem (see clause 5).

1.1 Basics terms for lane numbering

For the scope of this WorkItem, the terms *lane numbering* and *lane information* or *lane position* are defined as follows:

- *Lane numbering*: This term represents a numbering scheme that defines the association between
    - all available lanes of a road at a certain position (seen in a transversal section) AND
    - a unique number for each lane within this transversal section.
- *Lane information* or *lane position*: This term defines the currently used lane by an object or event, represented by the current number of the lane according to the *lane numbering*. The terms *lane information* and *lane position* are interchangeable within this document.

1.2 Example situation

The following Figure 1 and Figure 2 are an example and used to show different possible approaches for counting lanes. They show a part of a classical cloverleaf motorway junction in Germany without extraordinary complexity. The junction connects the A2 and A39 and is located between Brunswick and Wolfsburg (52.30923 °N, 10.72895 °E). It is just one of many junctions in Germany and similar ones probably exists in other European countries too.

Figure 1: Motorway junction A2 / A39 (Source: © OpenStreetMap-Contributors (see www.openstreetmap.org/ and www.opendatacommons.org/))

Figure 2: Motorway junction A2 / A39 with the highlighted area of Figure 1 (Source: © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Let's assume a vehicle follows the white path shown in Figure 2. With regards to the lane numbering and providing lane information, one of the first points to clarify is the counting direction. Some may count from the inner border (leftmost lane) to the outer border (rightmost lane / hard shoulder), some may count the lanes in reverse order (from outer to inner border). Some may also consider the opposite driving direction for counting (i.e., they count all available lanes). Left-hand and right-hand driving have to be considered as well.

Another point to clarify is the split of roads. Figure 2 shows an exit lane that starts right beside the regular driving lanes (it replaces the hard shoulder) and then diverges from the motorway. At some point, the exit lane can be considered as individual road, where an individual lane numbering should apply. But this point of ‘becoming independent’ has to be defined. The exit lane itself splits later again and requires again a definition when the lane numbering has to be restarted for the split lanes.

This example already shows discussion points and the need for a harmonized lane numbering approach. Beside motorways, other types of roads exist too. This results in the need to investigate different scenarios for different types of roads (see clause 3).

2 Already existing work to consider and limitations

Solving the issue with the lane numbering does not have to start from scratch. Some existing work to respect already exists. ETSI has defined a data element 'LanePosition' (see [RD-2], A.40 DE_LanePosition) that can be used by vehicle to inform other about their used lane. The element already defines the counting direction for lanes. It was discussed several times in the past and today's version is agreed between the C-ITS stakeholders. Therefore, the direction proposed by this element shall not be changed by the outcome of this WorkItem. In line with the element's definition, the counting shall be done from the innermost lane to the outermost lane, i.e., from the leftmost to the rightmost for right-hand traffic.

While the data element LanePosition was discussed and defined in the early days of the ETSI Release 1, there is no operational deployment that provides the data element until end of 2022 (initial version of this white paper). In the past, only the ETSI description would have to be considered, but with this white paper, additional clarifications and restrictions should be introduced. This type of semantically change could theoretically result in backward compatibility issues, but since the element was not used at all, there are no practical issues to consider.

2.1 Limitations

The construction of roads follows a lot of different rules across the world. An equivalent number of different road designs and building approaches exist. Furthermore, the layouts can differ heavily between urban and non-urban areas. The work for this WorkItem was not nearly sufficient to consider all of them. As a result, a subset for investigation was selected.

C2C-CC consists mainly of European members and stakeholder and thus, the WorkItem was limited to the European region with a focus on the non-urban environment. This environment covers mainly motorways and different types of rural roads. A brief look to intersection in the urban area was made as well, but the urban area was not under investigation in general. Future revisions of the document maybe cover more scenarios, including urban areas.

Furthermore, the lane numbering scheme to define shall be realizable by today's vehicles. The approach shall consider therefore state of the art technique that is already implement in today's vehicles or likely to be implemented.

3 Scenario-list for evaluation and validation

This chapter provides a list of scenarios that have been considered during the work of the working group. Each of the scenarios was used for the evaluation of the work and to validate the final approach. Due to the almost infinite number of existing real-world situations, a subset was selected. The scenarios show common but also challenging situation that shall be fulfilled by the approach to define.

3.1 Motorway junction

The motorway junction is located at the intersection of the motorways A2 and A39 in Germany between Brunswick and Wolfsburg. The coordinates are 52.30923 °N, 10.72895 °E. Figure 3 provides an overview of the junction.

The interesting part of this scenario is not the junction layout itself but the frequent changes of the lane numbering scheme by entering or existing lanes from the carriageways. Exit and enter-lanes are common along motorways in various designs. The essential concept of such lanes shall be covered by this scenario. The 'default' motorway without major changes and any other classical motorway layout can be also addressed with this scenario.

Figure 3: The motorway junction A2 / A39 between Wolfsburg and Brunswick. (Source: © OpenStreetMap-Contributors (see www.openstreetmap.org/ and www.opendatacommons.org/))

3.2 Split of the motorway

The motorway A2 in Germany is split into two separated carriageways for the same direction and merged again later. For this part, the entire motorway consists of a total of three, independent carriageways (separated by walls / guard rails). Each carriageway crosses the railway on a dedicated bridge. This situation is located close to Lehrte, the coordinates are 52.38965 °N, 9.97434 °E. Figure 4 and Figure 5 provide an overview of the related part of the

A2. A similar example is shown in Figure 6 but with a separation by a concrete wall, placed on the same road surface.

Such a split maybe affects the lane numbering scheme and shall be considered. Vehicles on one carriageway maybe not able to see or know how many lanes are available in total for one direction. Depending on the design approaches and rules for counting, they maybe have struggle to identify their correct lane number.

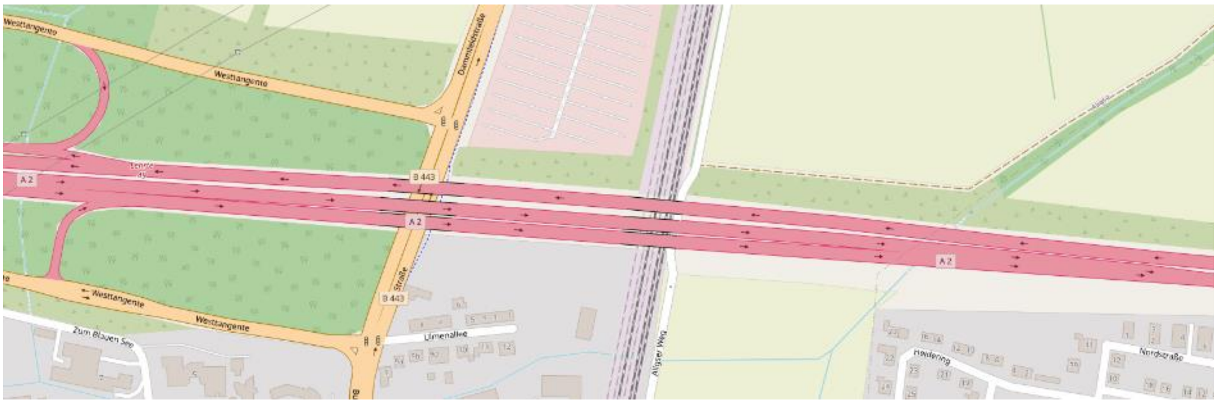

Figure 4: A split of the motorway A2, close to Lehrte. (Source: © OpenStreetMap-Contributors (see www.openstreetmap.org/ and www.opendatacommons.org/))

Figure 5: A split of the motorway A2 as aerial image, close to Lehrte. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Figure 6: Alternative situation for a split of a motorway (Source: https://www.aesys.com/products-solutions/traffic/variable-message-sign-vms.html)

3.3 Complex motorway junction

A complex motorway junction is built in the Netherlands, near Muiden and connects the A1 and A9 (see [RD-17]). It is stretched over a larger area, the part considered in this WorkItem is located at 52.33160 °N, 5.02920 °E and shown in Figure 7.

Basically, the motorway A1 goes from East to West and the motorway A9 is coming from the Southwest and connects to the motorway A1. The complexity is created due to the entry and exit ramps that connect different parts of the motorways. Furthermore, the median strip as central reservation (e.g. guard rails) of the carriageways contains another road / carriageway in between the regular carriageways. According to OpenStreetMap (see https://www.openstreetmap.org/way/775995424), this carriageway is 'reversible', meaning that the driving direction can change, see also Figure 8.

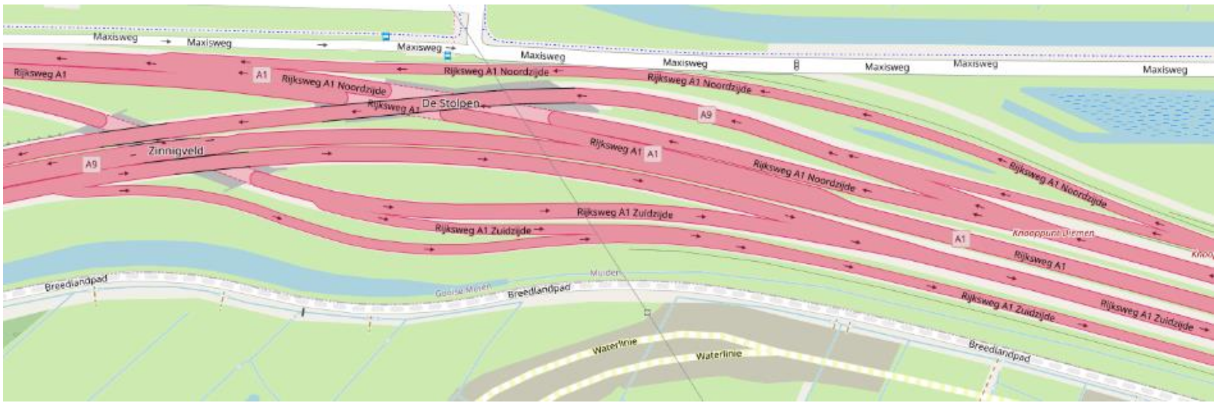

Figure 7: Th eastern part of the A1 / A9 motorway junction in Muiden. (Source: © OpenStreetMap-Contributors (see www.openstreetmap.org/ and www.opendatacommons.org/))

Figure 8: The revokable lanes of the motorway junction highlighted in yellow. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

3.4 Rural road

The B2, close to Potsdam (Germany), is an example of a rural road. The coordinates are 52.37240 °N, 13.05127 °E and Figure 9 provides an overview of a section of the road.

Rural roads can exist in a variety of setups. Roads with two or more lanes per direction and a separation between the driving directions can be handled like motorways and are not considered by an individually scenario.

This example of a rural road shows a change from a 2-lane-road (1 lane per direction) to a 3-lane-road, where the new lane for one direction is added to the left of the existing lane for that direction. So, the new lane is placed in the middle of the previous two lanes. The resulting lane numbering scheme shall be able to address this kind of changes.

Figure 9: A rural road where a new lane is added to the left of the existing lane. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

3.5 2+1 road

A 2+1 road consists of 3 lanes. Both outer lanes are continuously used for one traffic direction. The centre lane usage alternates, for some stretches of the road, the centre lane is used exclusively for one direction and later exclusively for the other traffic direction. Where the traffic direction changes, a restricted area (e.g. white shaded area) is placed over some distance on the centre lane to avoid accidents. The driving directions can be separated by physical separations, like guard rails, or just by solid lane markings. A scheme for such a road is depicted in Figure 10. A real-world example can be found at 58.45030 °N, 15.50708 °E and is shown in Figure 11.

This example was chosen to ensure that the lane numbering scheme to define can address changing lane usage.

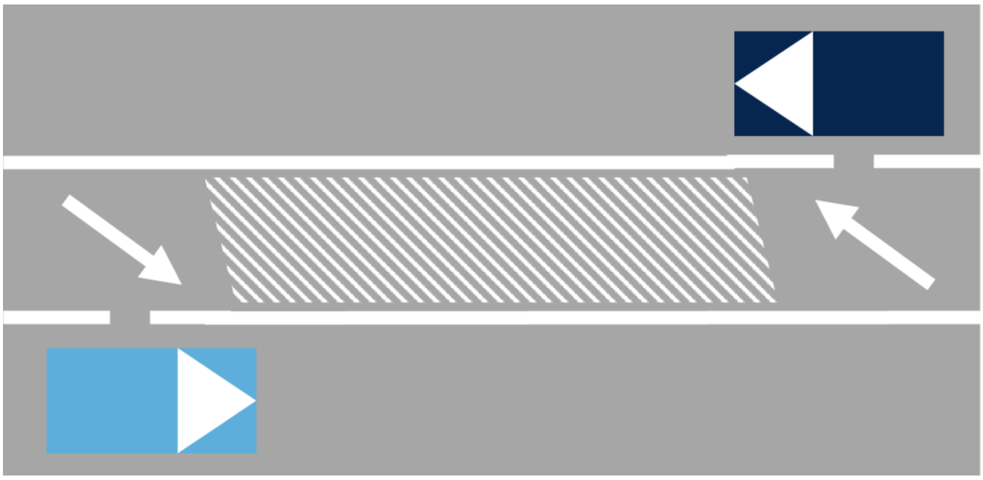

Figure 10: Scheme of a 2+1 road where the centre lane usage alternates and can be partially used by both traffic directions.

Figure 11: 2+1 road in Sweden with a physical separation between the opposing driving directions. (Source: https://commons.wikimedia.org/wiki/File:MMLNorr1.JPG)

3.6 2-1 road

A 2-1 road is somehow the opposite of a 2+1 road. On a 2-1 road, the shoulder lanes are reserved for pedestrians and cyclist, each side for a specific traffic direction. The vehicles for both traffic directions share the centre lane. During an encounter of two vehicles driving in opposite directions, they can sidestep on the pedestrian (shoulder) lanes when they are empty.

Figure 12 shows a scheme of such a road and a real-world example is shown in Figure 13, located near 56.11101 °N, 12.70099 °E.

The lane numbering scheme to define shall be able to provide a lane number also for such situations, where vehicles share the same lane.

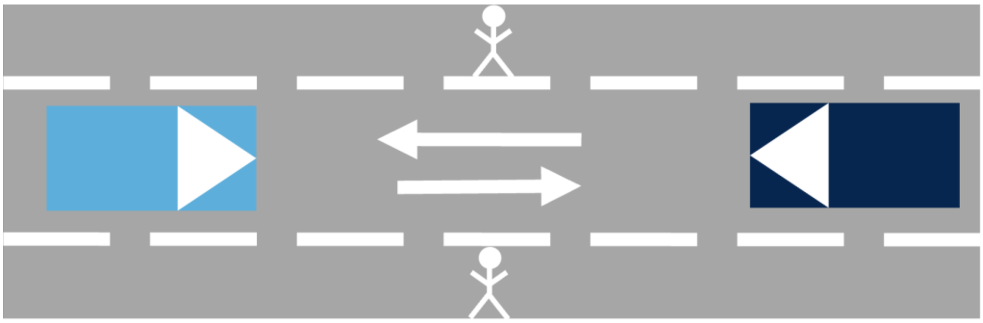

Figure 12: Scheme of a 2-1 road where the vehicles for both directions have to share the centre and the shoulders are used by pedestrians and cyclists.

Figure 13: 2-1 road in Sweden with a central, share lane for both traffic directions. (Source: © UFO-monumentet, https://commons.wikimedia.org/wiki/File:Bygdev%C3%A4g.jpg license: https://creativecommons.org/licenses/by-sa/4.0/deed.en ; No modifications)

3.7 3-lane road

The 3-lane road is similar to the 2+1 road. But instead of clearly separated traffic directions (e.g., by a solid line), the lanes are just separated by dashed lines, see Figure 14. The lane usage of the centre lane is handled differently in EU countries. For example, in Germany the centre lane can only be used by vehicles of both traffic directions for turning left but not for overtaking (see §7-(3a) in [RD-21]). In the United Kingdom, the centre lane can also be used for overtaking by both directions (see Rule 135 in [RD-22]). This can be quite dangerous and therefore, the lanes are sometimes also called ‘suicide lanes’. However, both rules agree that the outer lanes are exclusive for one traffic direction.

The challenge in this scenario is the shared use of the centre lane and the lack of a legal or optical separation of the traffic directions. The ETSI definition of the LanePosition element relies on this separation and a solution is needed.

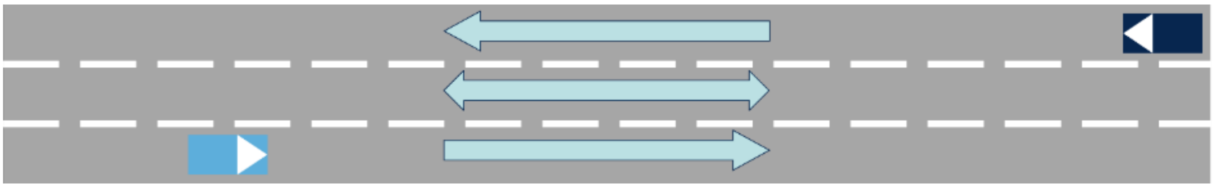

Figure 14: Example of a 3-lane road without clear separation of the driving directions.

3.8 Urban intersection

As mentioned in clause 2.1, urban areas were not in the focus of this WorkItem. However, the approach to define for a lane numbering should basically work in urban areas too and not fundamentally differ. Two completely different approaches, depending on being in an urban or non-urban area shall be avoided. Otherwise, both approaches have to be implemented and tested, which generates a lot of effort during the validation phase of product development and probably opens another set of issues. To ensure applicability of the defined approach, the working group decided to consider at least an urban intersection as additional scenario.

The selected intersection is crossing of the ‘Heinrich-Nordhoff-Straße’ and the ‘Major-Hirst-Straße’ in Wolfsburg, located at 52.42355 °N, 10.74815 °E, shown in Figure 15. The intersection is neither very small nor very large and has no too complex layout. Basically, there are 2 lanes per traffic direction going from east to west and 1 lane per traffic direction going from north to south. Another interesting aspect for the lane numbering scheme is the adding of lanes when approaching the intersection from the west. The road starts with two lanes, but later the road is extended by new lanes, added to the left **and** the right at almost the same position.

Figure 15: Urban intersection of the ‘Heinrich-Nordhoff-Straße’ and the ‘Major-Hirst-Straße’ in Wolfsburg. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

3.9 Roundabout

Roundabouts are another construction that can appear in non-urban and urban environments. The urban environment provides a larger variety of roundabouts than the non-urban environment. For the sake of this WorkItem, only a (simple) single lane roundabout is considered that appears in non-urban environments. Complex roundabouts with multiple lanes and maybe also with traffic lights appear most likely in urban areas. If traffic lights are present, a MAPEM and SPATEM can be disseminated by RSUs, like for ‘normal’ intersections and the roundabout can be handled like an intersection.

The selected roundabout for this WorkItem is a single lane roundabout and shown in Figure 16. The roundabout is located at 52.33052 °N, 13.17312 °E, in the surrounding area of Potsdam.

Figure 16: Non-urban roundabout. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

3.10 Potential future scenario for investigation

The following scenarios were contributed during the work but had not been added to this version of the document. They are maybe added to a future version:

- Diamond interchange (like at 55.36124°N, 10.34497°E)
- Different types of (multilane) roundabouts, like the one at
  - 48.14817 °N, 11.78675 °E
  - 48.16652 °N, 11.45461 °E
  - 48.75835 °N, 9.11630 °E
- An intersection on a rural road that would not generate SPATEMs and MAPEMs as intersection in urban areas can do.

4 Findings, definitions and expectations

The following chapter and clauses describe the approaches followed by the working group to define a lane numbering scheme. Where an approach was investigated but no solution, the challenges and reasons are described for discarding the approach (clause 4.1 and clause 4.2). The most suitable approach is presented in clause 4.3 and applied to the scenario of the previous chapter. The expected results for doing so are described in clause 4.4.

4.1 An approach based on the definitions of road related terms

As seen from the previous examples and problem descriptions, the lane numbering of a road can change – sometimes quite quickly. But there are also other pieces of a road where the same lane numbering applies to an entire piece over quite some distance. This led to the initial idea of this WorkItem, to split a road into pieces with equal characteristics (in terms of lanes) and use a lane numbering scheme for each of those pieces. A C-ITS-S would have to determine if it recently had change between two pieces and use the lane numbering scheme of the new piece accordingly. Such road-splitting requires clear guidelines when a piece ends and another one starts.

The first idea was to derive such guidelines from definitions of road related terms. If there is a clear definition for a piece with equal characteristics, the splitting criteria can be derived from the definition. The following sources for definitions of road related terms have been considered:

- Wikipedia (see [RD-4] & [RD-5])
- 'Vienna' Convention on road traffic (see [RD-6])
- German Road Law (see [RD-7] & [RD-8])
- ISO 17572-1:2021 (see [RD-9])
- ISO TS 14812 (see [RD-10])
- ETSI Teddy (see [RD-11])

The objective was to find answers for questions

- 'What is a road and what belongs to it (e.g. is a motorway with two separated driving direction a single road)?'
- 'What is a carriageway?' 'How many carriageways exists on different types or road (motorway vs. rural roads)'?
- 'What is a lane and how is a lane separated from other lanes'?
- 'How can a road be split into pieces'?

ETSI Teddy had only a definition for road, not for the other terms and was thus not further considered. The Vienna Convention contains definitions for roads, carriageways and lanes, but has no information for splitting them into smaller pieces. The same applies for the Germany Road Law, but carriageway is not explicitly defined there. Wikipedia provides a wide range of road related terms and definition. Probably, they reflect the 'common understanding' of such terms, but Wikipedia pages differ by language and can be changed without notice. This change-risks makes it hard to use Wikipedia as a single source of terms and definitions.

Only ISO 17572-1 and ISO TS 14812 contain definitions for all those terms, including definitions for smaller pieces of a road or carriageway. Unfortunately, both documents are not well aligned. Terms in ISO TS 14812 exists also in ISO 17572-1 but with a different meaning (see 'road segment' in both documents as an example). However, both documents share the same idea. While ISO TS 14812 is a common dictionary and offers a lot and very detailed definitions, terms in ISO 17572-1 are already used in other ETSI and C2C-CC documents (mainly with respect to the IVIM) but the definitions are a bit less detailed.

4.2 Why ISO TS 14812 is no solution

ISO TS 14812 provides a complete and detailed set of definitions. The working group decided to apply the terms onto two motorway scenarios (see clause 3.1 and 3.2) as an example to validate if the terms and definitions are clear and could contribute to a possible solution.

Before diving into the scenarios, the most important terms of ISO 14812 shall be introduced:

- A *road link* is a 'link representing a contiguous length of a road between two nodes of operational or managerial significance', whereby link, road and nodes are further specified in the document.
- A *road segment* is a 'link that represents a contiguous length of a road link characterized by the same physical characteristics'

Those two definitions allow a split of a road into pieces, called *road links*, and in even smaller pieces, called *road segments*. As a road segment has constant characteristics, the same number of lanes is available within a road segment. Thus, the same lane numbering scheme can be used for the entire road segment. If the total number of lanes changes, e.g. by an enter- or exit-lane, another road segment would begin. If a vehicle transitions from one segment to another one, the lane numbering scheme of the new road segment would apply to derive the lane information of the new segment.

These insights broke the initial problem of 'how to number lanes' into two smaller problems:

- Define a generic lane numbering scheme for a road segment with a constant number of lanes, and
- Define the begin and end of a road link and a road segment

The first problem depends on the general applicability of term road links and road segments. Therefore, the second problem is investigated first by applying the terms to scenarios. If the terms are applicable, the first problem can be addressed.

4.2.1 ISO 14812 applied to the scenario of clause 3.1

According to the definition in ISO TS 14812, the nodes of a *road link* shall be placed in such a way that they represent points with operational or managerial significance. What exactly qualifies a point to be of operational or managerial significance, is left open. This is a soft criterion. For the sake of this WorkItem, merging or diverging lanes, like enter- or exit-lanes, are considered as significant, because they represent points where the general road layout changes as well as the number of available lanes. Therefore, the working group assumed that the nodes for the road links are on such points. Following this approach, the motorway junction of clause 3.1 is split into smaller pieces as shown in Figure 17.

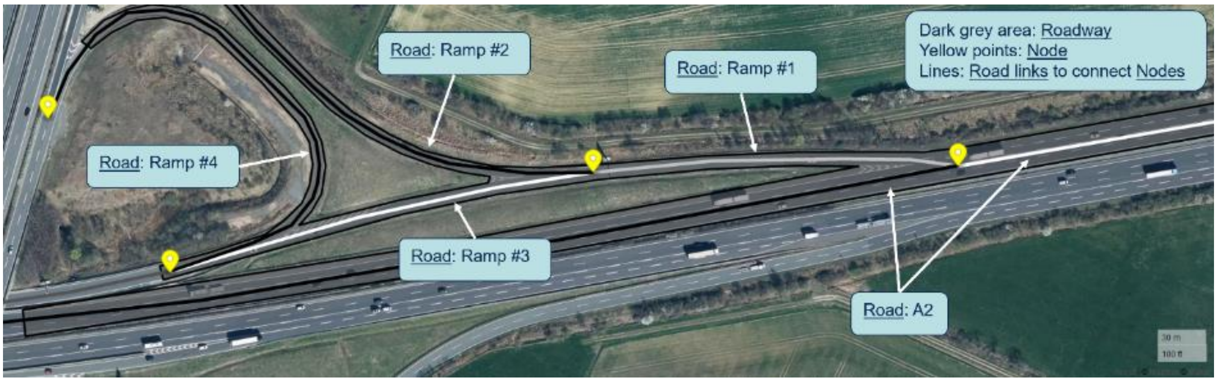

Figure 17: Scenario in clause 3.1 with yellow markers for the start and end points of road links and the different road links in between as white and black lines. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

When the road links are defined, they can be subdivided into road segments – the parts of a link with the same physical characteristics. However, the exact placement of the nodes is still open and can lead to different representations of the same part of the road and thus to different road segments. Looking at the first exit lane from the A2 (right most yellow marker in Figure 17), the existence of the grey road segments in Figure 18 depends on the placement of the node. In the left version in Figure 18, the node is placed where the exit lanes start diverging from the motorway. The grey segment in the middle is a short part where the motorway consists of 5 lanes. In the right version, the node is placed 'earlier' (on the motorway) and the grey segment is not present in this version. Two segments would exist in parallel, one with 3 lanes and the diverging road with 2 lanes. The same issue would apply also for other exit-ramps within this scenario and for other motorway junctions.

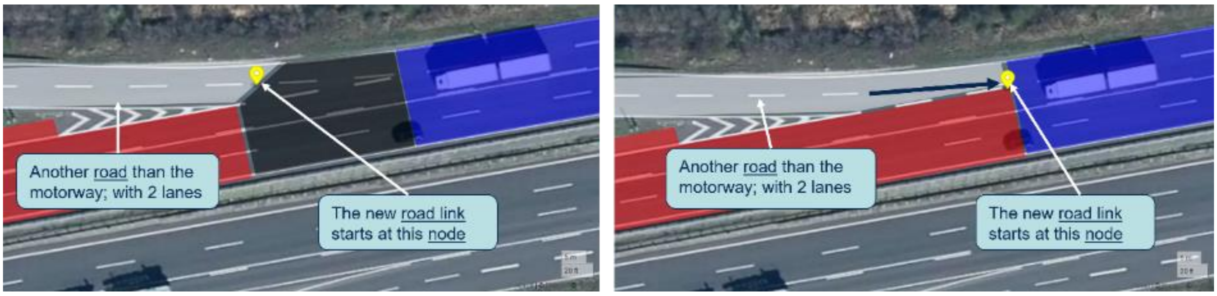

Figure 18: Scenario in clause 3.1 with two different versions for the available road segments, depending on the placement of the node for the road links. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

As seen in the example above, the placement of the nodes depends on the judgement of the map data provider. One provider with publicly available guidelines for mapping is OpenStreetMap (OSM). They maintain a wiki, where the applicable mapping rules can be found. With regards to splitting lanes, they state in [RD-12]:

'*If the number of lanes changes it is necessary to split the OSM way. This should be done as soon as:*

- *a new lane has started (regardless of width), or*
- *a lane has finished disappearing (usually a merge with another lane)*'

The OSM guidelines matches to the node placement of the right version in Figure 18. There the node is placed at the location where the second lane of the exit ramp starts according to the lane markings.

But OSM is only one provider. Other commercial providers may handle the issue differently, which make a unique handling of this issue unlikely. Unfortunately, public information about approaches of other providers had not been found. However, even if the working group would agree on a harmonized approach to use by all C2C-CC members, the group considered it as very unlikely that all other commercial providers would adapt all their data towards the C2C-CC view if they follow a different approach. This issue is a real burden for a solution based on definitions in ISO TS 14812, because it has an impact on the lane numbers at certain positions.

4.2.2 ISO 14812 applied to the scenario of clause 3.2

The road links and road segments of ISO TS 14812 have been applied to the second scenario as well. While this scenario does not have many entry or exit lanes, the split of the carriageway is another challenge. Before the split starts, the lane marking change from a dashed line into a solid line and later into a restricted area (see the yellow highlighted area in Figure 19). When the separated carriageway merges, the line markings are drawn in reverse order (restricted area → solid line → dashed line).

Figure 19: Scenario in clause 3.2 with yellow markers for the start and end points of road links and the different road links in between in white and black. The restricted area between the carriageways is highlighted in yellow. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Like in clause 4.2.1, the nodes shall be placed on points with operational or managerial significance. One map data provider maybe places the node already on the change from the dashed line to the solid line, another maybe places the node on the change from the solid line to the restricted area. A third one maybe even later where the physical separation begins (not shown in Figure 19).

The yellow marker in the upper (diverging) part of Figure 19 is aligned with the mapping of this scenario in OSM. In OSM, the node is placed close to the location where the dashed line marking becomes a solid line.[1] For the lower (merging) part, the OSM segment ends already earlier (on the solid line), whereas the yellow marker is placed where the solid line marking

[1] But still with some difference due to the mapping process and related position accuracy of the OSM data.

becomes a dashed line. The difference in this case is just about 140 m [2], but the node placement would lead to different road segments. A similar issue as already seen in clause 4.2.1. Where provider A already considers the part as ‘a single road with 3 lanes in parallel’, provider B maybe considers the same part as ‘2 lanes on one road in parallel to another road with a single lane’.

If, for example, a DENM would be placed in this area of merging carriageways, the processing of the lane information can be misleading. While vehicle C, using information from provider A, reports an event on lane 3, vehicle D, using information from provider B, does not know a lane 3. It is implementation specific if such information would be shown at all to the driver of vehicle D or if only the lane information would be omitted. To let the receiving vehicle D transform the mapping from originating vehicle C (whereby the source map data provider is unknown) into its own system is very complex and the testing effort for such an solution would be very high too. But such testing would be necessary and have to be done when such functions shall be used in a mass market vehicle.

4.3 The ADASIS approach

As described in clause 4.2, the split of a road into segments according to clear guidelines is essential and not trivial at the same time. Another approach to solve such issues was developed by the ADASIS organization (see [RD-14]).

ADASIS has developed and maintains a set of documents that defines a standardized interface for Advanced Driver Assistance Systems (ADAS) in a vehicle to access map data and related properties. Such data are usually stored in a proprietary format (depending on the map data provider) in the navigation system itself and the raw data are usually not shared with other applications. If the map data is shared, applications would still have to deal with different formats and would be hardly linked to specific map data providers. To overcome this state, ADASIS defined a common interface to describe those map data in detail and a technical solution to share the data across different in-vehicle control units. This sharing in a common format makes the data available to driver assistance and automated driving functions and independent of the map data provider. The receiving unit / system or user of the data can just rely on the ADASIS format and does no longer have to deal with any provider specific solutions. It is then the responsibility of the provider to transform their data into the ADASIS format.

Having such an approach as a common solution for multiple stakeholders, requires a wide range of supporters. The ADASIS organization has a lot of members from the automotive industry, including:

- Vehicle manufacturers
- Navigation system manufacturers
- ADAS manufacturers
- Map and data providers

[2] Even the best implementations will probably not achieve a perfect match of their nodes, but the difference should be as small as possible.

The full list of members can be found at [RD-14]. This large number of automotive industry members can be seen as a sufficient base to consider the ADASIS approach as possible solution of this WorkItem.

Alternatively, to ADASIS, some vehicle manufacturers maybe use the same general concept of ADASIS but in a proprietary implementation. This solves the issue of sharing the data within a vehicle, but the receivers are still manufacturer specific.

4.3.1 How the ADASIS approach works

The ADASIS specification can provide map data with a high number of details. The first and most important information is the plain structure of a road and intersecting / linked roads. This includes for example the detailed course of the road (geometrical description), structural properties (like tunnels or bridges), the number of available lanes and the driving direction per lane. The ADASIS specification allows also sharing of additional information for parts of the road or segment, like traffic signs (e.g., speed limits), traffic lights or the road surface. [RD-15] defines the full list supported properties, called *profiles* in ADASIS.

Like the approach based on ISO TS 14812, the ADASIS approach also splits a road into smaller segments. Instead of defining certain points with soft criteria, ADASIS follows the lane markings (or the lane boundary in general) on the road to split a road into segments whenever the lane markings change. Their approach is defined in [RD-15], clause 3.4.5.10:

> '*An ADASIS v3 Horizon Provider shall start a new Lane Model entry when the number of lanes or a lane property changes. A road segment is cut and a new Lane Model entry is started in the following situations:*
>
> - *Lane connectivity changes, e.g., at an intersection, when a lane starts anew or a lane starts forming or a lane ends or a lane ends merging into another lane.*
> - *Physical divider or lane boundary between lanes starts or ends.*
> - *One of the lane boundary types changes.*'
>
> Note: An 'ADASIS v3 Horizon Provider' is the component that translates the underlying map data into the ADASIS format and broadcast it via in-vehicle networks to other components. A 'Lane Model' is the ADASIS representation of a lane with various attributes.

Based on this approach, a road is split into segments with a constant number of lanes. The lane numbering with a segment is specified by ADAISIS as well, define in [RD-15], clause 3.4.5.9:

> '*Lanes are counted beginning with 1 from outmost to midmost in the direction of the lane including shoulder and other lanes (i.e., counting start from the rightmost lane for right-hand traffic and from the leftmost lane for left-hand traffic).*
>
> *[…]*
>
> *An ADASIS v3 Horizon Provider shall include a description for all lanes of a road including all carriageways and both directions for a bidirectional road.*'

With the segmentation approach and the lane numbering within a segment, a general lane numbering scheme can be created. Before doing so, the ADASIS approach is applied to an example to validate its applicability and to get an impression of the rules, see clause 4.3.2.

ADASIS also specifies connection information between segments, describing how the lanes of one segment continue in the next / following segment. This information is useful for a receiver when he would receive information about an object or event on a specific lane ahead of itself via V2X messages. The receiver can use the absolute position to identify the segment where the source is placed on. Then, the receiver can use the connection information to evaluate if the object is on the same lane as he currently is or an adjacent lane.

Comparing the plain lane numbers is only sufficient if both segments contain the same number of lanes. Otherwise, if the next segment has more or fewer lanes than the current segment, the lane numbers of one segment cannot be transferred directly to another segment. Clause 4.4.4 contains an example and description for this case more in detail.

4.3.2 An example based on the ADASIS approach

The scenario in clause 3.1 was selected as example for applying the ADASIS segmentation rules. The driving direction is East to West (i.e., right to left). An overview of the results is shown in Figure 20. The scope of the ADASIS specification is the in-vehicle-domain. All parts of a road (network) are described from the ego vehicle perspective. In this example, the imaginary ego vehicle is in the white segment at the right border and follows the depicted driving direction, all segments in the figure are ‘ahead’ of the ego.

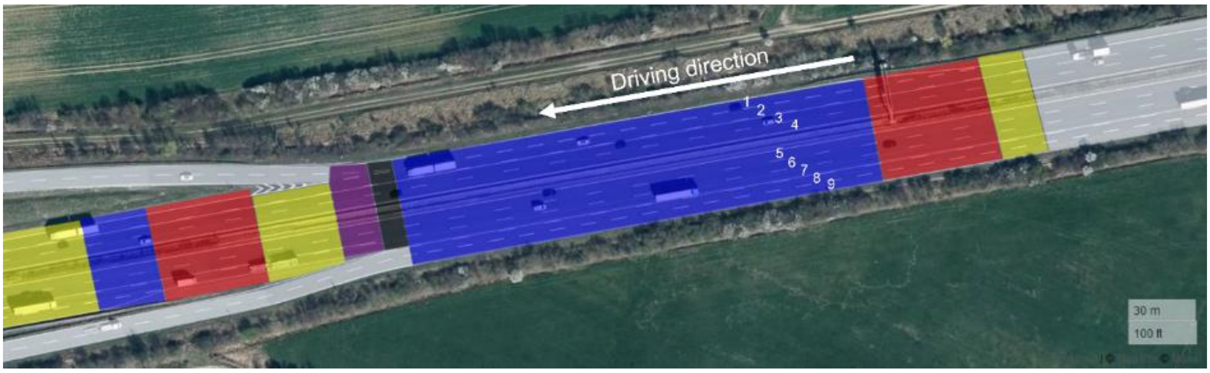

Figure 20: Coloured overlay of the A2 showing the road segmentation according to the **ADASIS** rules. The general driving direction and lane numbering for one segmented are added. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

The **white** overlay at the right border of the figure is the initial segment with 3 regular driving lanes and a hard shoulder. The **yellow** segment aside is created due to the changed lane marking between the outermost and the middle regular driving lane. The lane marking changes from a dashed line to a dashed line in parallel to a solid line. The following **red** segment represents the part where the exit lane opens but is not fully open yet. This is a change in the lane marking and in the connectivity between the segments. The exit lane replaces the previously existing hard shoulder lane. As soon as the exit lane is fully opened, a new segment starts, the **blue** one. While the change from an ‘opening lane’ to a ‘fully open lane’ is not directly a change in the connectivity or of the lane boundaries, this approach of two segments for an opening lane is also used in [RD-16], clause 8.1.1. The following **grey** segment marks the start of a second exit lane according to the lane markings (exit ramp has a total of 2 lanes), in between the already existing exit lane and the outermost regular driving lane of the motorway (changed lane markings and connectivity). The grey segment and the following **purple** segment are very similar but separated, because in the purple segment the hard shoulder lane of the opposite direction closes (ADASIS also consider changes on the opposite direction of a road). One may discuss if this tiny part of the hard shoulder on the opposite carriageway justifies an individual segment or if the grey and purple segment could be combined.

Following the main direction of the motorway, the second **yellow** segment in the figure represents the part of the road where neither an exit lane nor a hard shoulder lane is present on the carriageway for the considered driving direction. The motorway lanes are separated from the exit ramp via a white shaded area. This is a changed connectivity and a changed lane boundary. Afterwards, a new hard shoulder lane begins, which is covered by the second **red** segment (changed connectivity). The second **blue** segment is caused by the closing lane on the opposite direction, which is fully open in the final **yellow** segment.

The exit ramp of the considered driving direction is shown as **white** segment and connects with the purple element before. The number of lanes or the lane boundaries are unchanged in the exit ramp and so this part is modelled as a single segment. The same applies for the entry lane of the opposite driving direction, also shown as **white** segment in the lower part of the figure.

Based on the ADASIS rules, the ambiguity faced with ISO TS 14812 (see clause 4.2.1) can be avoided. The lane markings provide clear guidance where to split segments.

As seen from the figure and the segmentation before, every segment has a constant number of lanes in it. For the lane numbering example, the first, long blue segment of Figure 20 was selected, but any other segment could have been used as well. According to the ADASIS specification, every lane is counted, including hard shoulders and the lane of the opposite driving direction, which maybe cannot be reached by all vehicle of one driving direction. In Germany, right-hand traffic applies, so the counting starts with 1 for the outermost lane (i.e. right most lane) in the direction of travel. For the blue segment, this is the exit lane that becomes lane number 1. The other lanes are counted towards the middle of the transversal section of the road. The outermost ‘regular’ driving lane has lane number 2, the innermost driving lane for the shown driving direction has lane number 4. Then, the counting continues at the part for the opposite direction. The innermost lane of the opposite direction has lane number 5, the outermost is lane number 9.

The ADASIS counting is done from the ego-vehicle’s point of view. So, a vehicle driving on the opposite carriageway, would receive swapped lane numbers from its ADASIS system, see Figure 21 for an example.

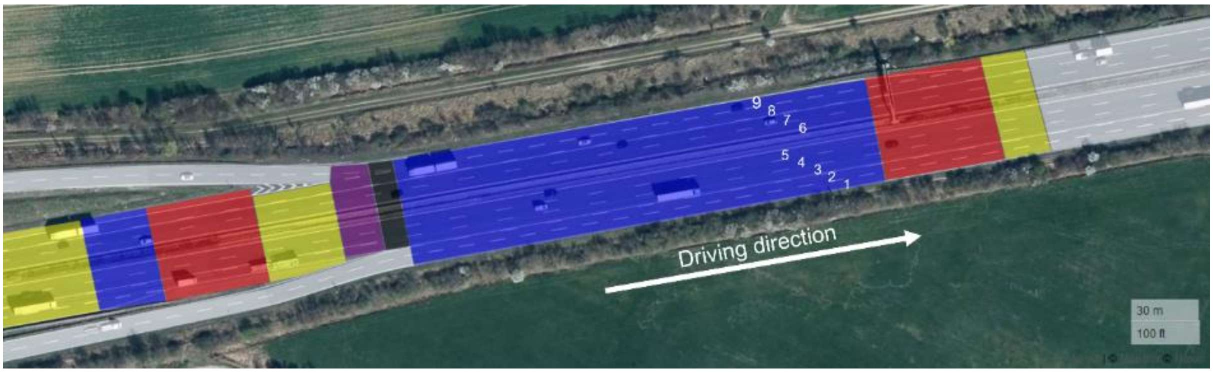

Figure 21: The **ADASIS** counting for the example in Figure 20 but for the opposite driving direction. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

According to the specification, the lanes are counted per segment. If the transversal section of the road would be moved to the yellow segment in between the purple and red segment, the transversal section covers all parts and would include the entry and exit ramps (see solid white line in Figure 22). But the entry and exit lanes are individual segments and are counted individually. Both, the entry and exit lane, would have lanes with number 1 and 2, the yellow segment would also have lanes with the number 1 – 7, shown in Figure 22.

Figure 22: The solid white line represents the point for the transversal section of the entire road. The **ADASIS** lane numbers for the 3 segments at this transversal section are added. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Further examples for the ADASIS lane numbering are given in the following sections, where necessary.

- Figure 29 shows the ADASIS lane numbering on a motorway with a physical separation for the same traffic direction.
- Figure 42 shows the ADASIS lane numbering on a road with a reversible lane.

4.3.3 Defining a lane numbering scheme

While the ADASIS approach provides a well-defined lane numbering scheme, this approach cannot be taken over without changes. Within ETSI, discussions had been taken place about the numbering scheme to use (see chapter 2). The result is a lane numbering scheme that counts all lanes per carriageway, per traffic direction (see element 'LanePosition' in [RD-2]) and can be considered as **normative target scheme**. ETSI's counting direction is from the inner hard shoulder (if existing) → to the leftmost lane → to the rightmost lane → to the outer hard shoulder (for right-hand traffic), i.e., the opposite direction of ADASIS. As this is the agreed scheme in ETSI (and a lot of discussion about this item in the past), the ETSI scheme cannot be changed easily.

This twisted logic has to be addressed by a transformation between the lane numbering schemes used in ADASIS and ETSI. The working group identified such a transformation algorithm:

1. Select the segment where the ego vehicle is currently driving on, by mapping the ego/reference position contained in the C-ITS Message (CAM, DENM, etc.) to the ADASIS map. Exit here, if the semi-major axis length of the actual positioning accuracy ellipsis (at 95%) is greater than 3 meters.

2. Select all lanes of this segment that follows the ego's driving direction[3]
   a. Note: this includes lanes exclusively used by one direction as well as lanes that are shared / used together with the opposite driving direction
3. If the segment has LinearObjects of type 'fence', 'wall', 'guardrail', 'curb' or a LaneMarking of type 'shaded area' in between the selected lanes[4]: Select a subset that:
   a. contains the lane where the ego is driving on and
   b. contains all adjacent lanes between the two closest borders. Note: a border is: either the road boarder, the opposite driving direction or a 'fence', 'wall', 'guardrail', 'curb' or a LaneMarking of type 'shaded area'
   c. Continue with the selected subset of lanes. If the lane is derived directly from an absolute position and the subset consists of only one lane whose width is less than the actual lateral positioning accuracy (at 95 %), then exit (i.e., no lane information can be provided).
4. If the lane with the lowest ADASIS lane number is of type 'RestrictedForbidden' or 'DrivableShoulder', assign ETSI LanePosition 14 to it[5]
5. If the lane with the highest ADASISI lane number is of type 'RestrictedForbidden' or 'DrivableShoulder', assign ETSI LanePosition 0 to it
6. Initialize a counter ETSICounter with 1
7. For all remaining lanes without an ETSI LanePosition:
   a. Take the lane with the highest ADASIS lane number that has not been processed yet; assign the value of ETSICounter as ETSI LanePosition to it
   b. Increment ETSICounter; Repeat step 7 for all remaining lanes
8. (Store association LaneNumber <-> ETSI LanePosition for future retrieval)

This algorithm was designed with two general implementation-approaches in mind:

- Using an 'average' positioning solution (i.e., lane level accurate positioning is not given) to map the ego onto a segment and derive the currently used lane from camera-based image processing and map data.
- Using a high-performance positioning solution that provide more than lane level accuracy and derive the lane information from the absolute position and map data.

A lane level accurate position could be derived from the 'average' lane width. In Germany, the lane width can vary between 2.75 m and 3.75 m and depends on the general road type. While the road type could be read from map data, the value would still vary depending on the currently

[3] Lanes in ADASIS have an attribute for the driving direction relative to the ego.

[4] LinearObject is an ADASIS type to describe elements running in parallel to a lane.

[5] The working group assumes that a non-driveable hard shoulder lane is of type 'RestrictedForbidden' in ADASIS, but the ADASISI specification (see [RD-16]) did not contain a specific description for this today.

used road. Instead, the lane level accuracy should be derived from the maximum vehicle width. This value is road type independent and usual lanes should at least have this width. In the Germany, this is defined as 2.55 m for default vehicles (see [RD-24]), which would be the majority of all vehicles. As a result, if the semi-major axis length is less than 1.27 m, a lane level accurate position can be assumed.

Figure 23 is a supporting image for going through all the steps in the next paragraph. The counting scheme for the lanes are depicted in each sub-figure. As step 1, the correct road segment has to be selected, where the ego vehicle (or the remote vehicle under question) is driving on (see Figure 23, left part). If the accuracy in lateral or longitudinal direction is too low, a proper mapping might not be possible. Only when a mapping is possible, lane information should be provided. This also mean that a vehicle is allowed to provide lane information while being in a tunnel as long as the position accuracy requirements are fulfilled. As the ETSI LanePosition covers only one driving direction, the lanes on the opposite carriageway does not have to be considered any further (Step 2, see Figure 23, middle part). The 3. step is necessary to support scenarios like in clause 3.2, where a motorway carriageway for one driving direction splits, see clause 4.4.1 for details. This step also supports reversible lanes where the currently applicable driving direction is unknown. The steps 4 and 5 transform an outer hard shoulder lane and an inner hard shoulder lane (which can exist in some countries). As an example, in the middle part of Figure 23, a hard shoulder exists and has the lane number 1. This lane has to be transformed using step 4, which turns the lane into LanePosition 14 according to ETSI. The steps 6 and 7 transform all the regular driving lanes from the lane numbering in ADASIS to LanePosition according to ETSI, starting from the innermost driving lane (see Figure 23, right part). Simpler, they invert the ADASIS counting direction to match the ETSI requirement. The final step 8 is optional and can help a receiver to map remote objects onto its ADASIS-model if he receives CAMs that include lane information and the receiver has already processed this segment before.

Figure 23: Example of the transformation algorithm, based on an imaginary ego within the segment. The white segment of this figure corresponds to the long blue segment in Figure 20. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

As shortly indicate in the paragraph above, the steps in algorithm can also be used to place a received CAM or DENM of another vehicle onto the ego's ADASIS map. Based on the absolute position in the message, the related road segment(s) can be selected and the ETSI LanePosition of the message can be transformed back into an ADASIS lane assignment based on the rules of the algorithm (Step 2 to Step 5). Then, the ego vehicle can easily check if the other vehicle is located on the same lane or on an adjacent lane. Messages with a heading information eases the process a bit by selected the correct driving direction. Messages without heading (e.g., generated by an RSU) but an accurate position can be addressed this way as well. An accurate position helps the receiver to select the correct segment and lane.

For this reverse-procedure, the receiver could be interested in the method how the originator created the lane information (e.g., from camera or absolute position). This information cannot be shared with other traffic participants today. If there is a true interest in this information, ETSI should add this information to the C-ITS messages.

4.4 Expectations for the scenarios of chapter 3

The previous clause described the ADASIS approach and a transformation from the ADASIS numbering scheme into the ETSI scheme. This clause discusses the initially selected scenarios more in detail and defines the expected outcome for each of them. The following figures indicates the driving direction of an imaginary ego vehicle. The numbers within the figures show the expected ETSI LanePosition that a vehicle should put into its CAM while driving in the related segment. The transformation algorithm of clause 4.3.3 was used to create those ETSI LanePositions, but the application of the algorithm itself on the scenarios is not described again in detail.

Furthermore, please note that all the segments in the figures are a result from applying the ADASIS rules (see clause 4.3.1) onto the scenarios. None of the segments or a segment identifier is transmitted over the air via V2X messages like CAM or DENM. Only the resulting lane number of a specific vehicle is shared. All the complexity related to handling all the segments is a vehicle-internal task.

4.4.1 Motorway junction

For the scenario in clause 3.1, four subsections are selected and described more in detail:

- The begin of the exit lane that replaces the hard shoulder
- The part where the second exit lane starts
- A part on the exit ramp where a new lane diverges
- A part on the exit ramp where two lanes merge

The general road segments of the motorway are already described in chapter 4.3.2 and only the justification for the additional road segments on the exit ramps are described in this clause.

The begin of the exit lane that replaces the hard shoulder

The road segments and expected ETSI LanePositions for the begin of the exit lane are depicted in Figure 24. The difference between the white and yellow segment is only the changed lane marking in between the middle lane and the rightmost lane. This is a good example that new road segments do not always go in line with more or fewer lanes. Both segments can be considered as a ‘normal’ motorway, with three lanes in parallel (ETSI LanePosition 1-3, with 1 for the innermost driving lane) and a hard shoulder at the border (ETSI LanePosition 14). ADASIS provides the necessary information to identify a hard shoulder lane. The red segment marks the start of the exit lane, where the exit lane opens, but is has not reached the default lane width. The exit lane replaces the hard shoulder, which is reflected by a change lane numbering. The former hard shoulder lane becomes ‘regularly drivable’ and the

ETSI LanePosition changes from 14 to 4. The blue segments starts as soon as the exit lane has reached the default lane width and remains constant, there are no other differences to the red segment. As a result, the blue segment uses the same lane numbering as the red segment.

Figure 24: ADASIS-road segments for the scenario in clause 3.1 (where the exit lane starts) with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

The part where the second exit lane starts

The road segments and expected ETSI LanePositions for this part of the motorway junction are shown Figure 25. The blue segment at the right border of the figure is the same as before in Figure 24. The following grey and purple segments describes the same situation for the carriageway of the considered driving direction – the difference for the segment split is on the carriageway of the opposite driving direction. Both segments cover the part where the second exit lane starts in between the rightmost lane of the motorway and the existing exit lane, as indicated by the lane marking on the surface. Due to the position of the new lane, this new lane becomes ETSI LanePosition 4 and the already existing exit lane changes from ETSI LanePosition 4 into 5.

After the purple segment, the road splits. The white exit ramp is separated from the motorway by a white shaded, restricted area and continues independently of the motorway. The exit ramp becomes an individual carriageway / surface and has from that point on its own road borders. As the white segment is located on a new carriageway and according to the definition of the ETSI LanePosition (counting per carriageway, per driving direction), the lane numbering for the white segment is independent of the lane numbering on the motorway. The innermost (leftmost lane) on the exit ramp becomes ETSI LanePosition 1 (ETSI LanePosition 4 in the purple segment before). The other lane becomes ETSI LanePosition 2 (ETSI LanePosition 5 in the purple segment before).

The yellow segment lacks a hard shoulder and the 3 already existing regular driving lanes continue in this segment with the ETSI LanePosition 1 - 3. Again, ETSI LanePosition 1 is used for the innermost lane and 3 for the outermost lane. In final red segment, a hard shoulder starts again and is included in the lane numbering scheme. This hard shoulder becomes ETSI LanePosition 14.

The white shaded, restricted area in between the white and yellow segment is not considered to belong to any of the segments. In such cases, it is a safety margin to separate the carriageways.

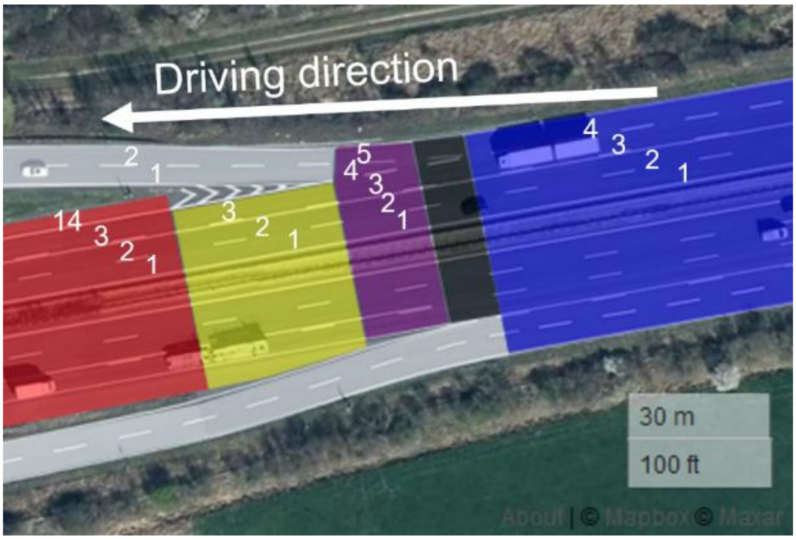

Figure 25: ADASIS-road segments for the scenario in clause 3.1 (where the second exit lane starts) with the expected **ETSI** LanePositions. The purple and grey segment use the same lane numbering, but it is not shown for the grey segment due to readability. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

The part on the exit ramp where a new lane diverges

Following the white segment in Figure 25 (the exit ramp), leads to another split of the exit ramp's carriageway, see Figure 26. As soon as the new exit lane is indicated via the lane markings, the red segment starts. The red segment consists of 3 lanes, whereby the new lane opens and only reaches the full regular lane width at the end of the segment. The newly opened lane needs an ETSI LanePosition and as it is only added to right of the outermost lane, the new lane becomes lane 3 in terms of ETSI LanePosition, without renumbering the existing lanes (as it is added to the outside of the lane with the highest ETSI LanePosition of the previous segment). After the red segment, the carriageway splits into a north-west direction (grey segment) and a south-west direction (blue segment), comparable to the situation in Figure 25. This split of the carriageway is accompanied by a change of the lane boundaries (separated by a restricted area) and results in two new ADASIS segments. The new grey segment has a single lane, becoming ETSI LanePosition 1. The blue segment can be considered as continuation of the main lanes of the white (and red) segment and uses the same numbering scheme – the leftmost lane becomes ETSI LanePosition 1, the inner, second lane becomes ETSI LanePosition 2.

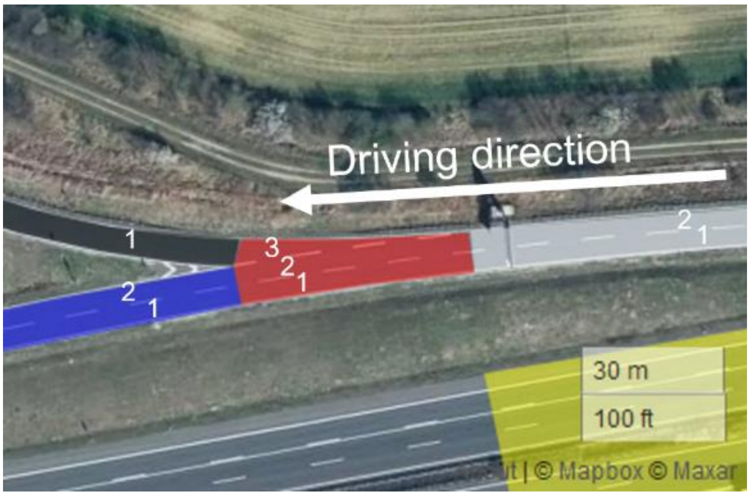

Figure 26: ADASIS-road segments for the scenario in clause 3.1 (where the exit ramp splits) with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

The part on the exit ramp where two lanes merge

Figure 27 shows the continuation of Figure 26, the blue segment at the right border represents the same piece of the carriageway and uses the same lane numbering scheme as before. The following yellow segment initially consists of 2 lanes, but the outer (rightmost) lane is closed within this segment so that only one lane continues in the white segment (changed connectivity). The lane with ETSI LanePosition 2 disappears and only the innermost lane with ETSI LanePosition 1 continues. The white segment is one of two incoming-connections of the following grey segment (guarded by a white shaded, restricted area). The other connection is the blue segment, starting at the top border of the figure. This blue segment is a single lane on an independent carriageway and has its own lane numbering scheme, making the single lane ETSI LanePosition1. As a result, the grey segment represents a changed connectivity for the white and blue segment, because the former individual lanes / carriageways are merged into a single carriageway. In alignment to the split-scenarios before, the restricted, white shared area is considered as a split for the carriageways. The solid white line in the grey segment does no longer split them into individual carriageways, both lanes are now a single segment. This new carriageway results in a restart of the lane numbering. The lane with LanePosition 1 of the white segments continues to be ETSI LanePosition 1 and the lane from the blue segments becomes ETSI LanePosition 2. When the solid line changes to a dashed line (changed lane boundary), the grey segment ends and the red segment starts. Since no lane is added or removed nor any physical separator between the lanes exists, the lane numbering scheme of the grey segment is taken over.

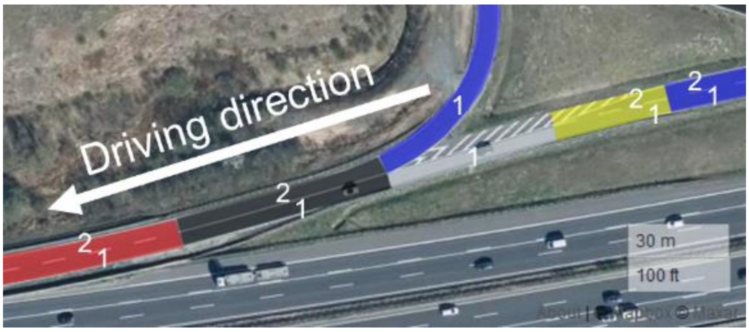

Figure 27: ADASIS-road segments for the scenario in clause 3.1 (where two lanes merge on an exit ramp) with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

4.4.2 Split of the motorway

For the scenario in clause 3.2, three subsections are selected and described more in detail:

- The begin, where the carriageways diverge
- The centre, where a physical wall separates the lanes for the same driving direction
- The end, where of the carriageways merge

The parts in between are not considered.

Beginning segment

The road segments and expected ETSI LanePositions for the begin are shown in Figure 28. The initial, white segment can be considered as a ‘normal’ motorway, with three lanes in parallel (ETSI LanePosition 1-3; the innermost driving lane becomes ETSI LanePosition 1) and a hard shoulder at the outer border (ETSI LanePosition 14). The following yellow segment is caused by the changed lane marking from a dashed to a solid line between the leftmost and the centre lane. Such type of lines can occur on motorways and more often on rural road. After some distance they can change back to a dashed line. Those changes do not have to be treated in a special way. As a result, the same ETSI LanePositions are used as in the white segment. The third, purple segment indicates the change from the solid line to a restricted, white shaded area between the leftmost and centre lane. Such areas are another type of lane marking, even when the related traffic rule does not differ from a solid line (both shall not be crossed by vehicles).

However, in contrast to the solid line, those shaded areas are usually placed when a road diverges from or merges with another road. In this example, this is a diverge of a new carriageway from the existing carriageway. On that new carriageway, an individual lane numbering scheme shall be used, as the ETSI lane numbering is done per carriageway per driving direction (see [RD-2], A.40 DE_LanePosition). This is basically the same principle as used in clause 4.4.1, see Figure 25 for example (diverge of an exit ramp). In brief, the carriageway splits as soon as the white shaded, restricted area starts. As a result, the northern lane (in between the central reservation and the shaded area) becomes ETSI LanePosition 1. On the other carriageway (bounded by the restricted area and the outer road border), the most norther lane becomes ETSI LanePosition 1 as well. The southern, second regular lane becomes ETSI LanePosition 2 and the hard shoulder remains ETSI LanePosition 14.

This separation is also address in the transformation algorithm in clause 4.3.3. When using ADASIS data, step 3 of the transformation rules becomes relevant now. This step uses the information of an ADASIS segment to split the carriageway accordingly, even if ADASIS treats it as a single carriageway. The new borders for the two carriageways are the road boarders and the white shaded area (and later the wall) in the middle. This step ensures that a vehicle driving on the middle carriageway uses another lane numbering scheme than a vehicle on the lower carriageway. In such situations, both carriageways are treated as independent (in term of ETSI lane numbering) and uses their own lane number scheme to comply to the ETSI scheme. Such a split result in two lanes with ETSI LanePosition 1 in parallel, separated by a white shaded area (and later a concrete wall).

Besides a (concrete) wall, other suitable separators are different types of fences or guardrails. A temporary concrete wall, like Jersey barriers in roadworks zones, was considered by the working group also as a wall and would result in the same situation as described here.35

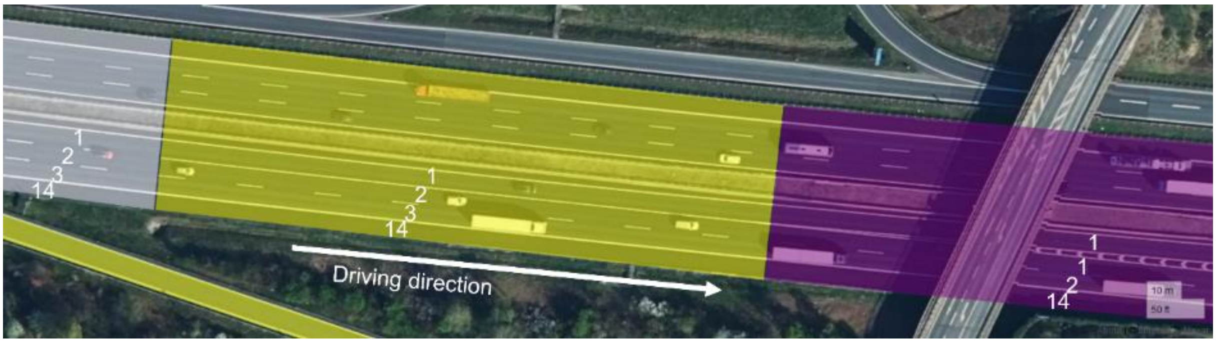

Figure 28: ADASIS-road segments for the scenario in clause 3.2 (where the lanes diverge) with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Middle segment

In Figure 29, the road segments and the related ADASIS counting are shown. As described in clause 4.3.2, in ADASIS all lanes of a road a counted, regardless of the driving direction. This initial lane numbering has to be translated into ETSI. The expected ETSI LanePositions for the middle part are shown in Figure 30, where the carriageways are separated by a restricted, white shaded area and later by a wall.

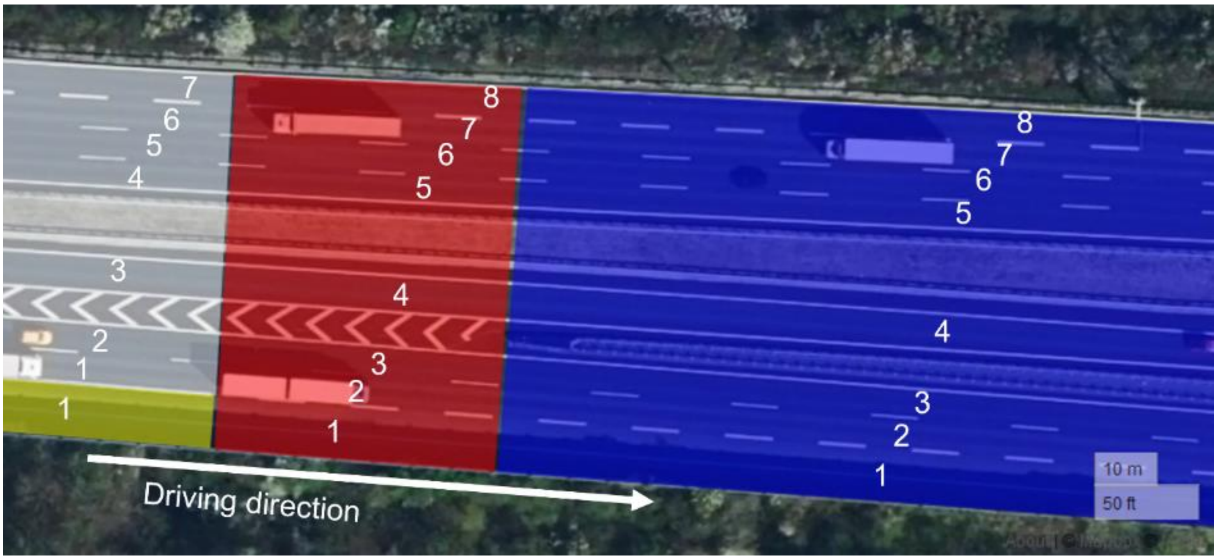

Figure 29: ADASIS-road segments for the scenario in clause 3.2 (where the lanes are separated from each other) with the **ADASIS** lane numbering. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

The white segment depicts the existing motorway, like the purple segment of Figure 28 and with similar ETSI LanePositions. The carriageways are already separated by the white shaded, restricted area. The yellow lane at the bottom is not a hard shoulder, it is an entry lane for the motorway that has not yet merged with the motorway. Since this is a single lane on an individual road (not yet merged), the ETSI LanePosition 1 is used. Here, two lanes with ETSI LanePosition 1 exists in proximity and a receiver shall take care of this issue when using the ETSI LanePosition of a remote vehicle in one of those segments. The following red segment is the merge of the white segment and the entry lane (yellow segment). This represents a change in the connectivity of the segments. In the red segment, the motorway consists of two carriageways, one with one lane and the other one with 3 lanes. The former entry lane with ETSI LanePosition 1 becomes a lane with ETSI LanePosition 3. The separated carriageway with a single lane is handled in the same way as before. The blue segment marks the begin of the physical separator (in this case a concrete wall) between the carriageways. This physical separator replaces the white shaded area and cannot be crossed anymore. With regards to the lane numbering, the physical separator is another type of separation and forces an individual lane numbering (see step 3 in clause 4.3.3). As before, the two carriageways run in parallel into the same direction.

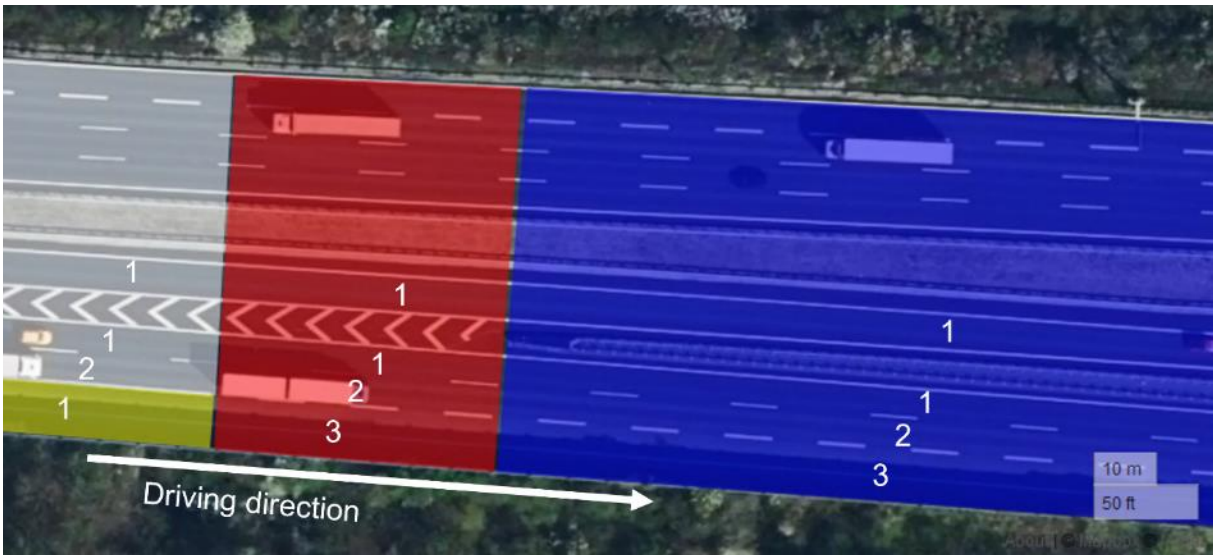

Figure 30: ADASIS-road segments for the scenario in clause 3.2 (where the lanes are separated from each other) with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Final segment

The final segment of the scenarios is the part where the lanes are no longer divided by a separator and merge into a single carriageway. The ADASIS segments and the expected ETSI LanePositions are shown in Figure 31. The white segment represents the part of the road with two carriageways in one direction, like the blue segment in Figure 30. The same numbering applies as for the middle part before, beside that the third lane on the lower carriageway had changed into a hard shoulder with ETSI LanePosition 14. The white segment ends with the physical separator and the yellow segment starts, where the lanes are only separated by a white shaded, restricted area. Like in the beginning of this scenario (purple segment in Figure 28), a restricted area is also a separator and both carriageways are still considered as individual carriageways. Step 3 of the transformation rules in clause 4.3.3 still applies and reduce the lanes to subsets. Since this segment does not have any other changes, the same lane numbering as for the white segment applies for the yellow segment. Afterwards, in the blue segment, the restricted, white shaded area is replaced with a solid line. As in the begin of the scenario, a solid line does no longer separate the carriageways. As a result, the independent ETSI lane numbering of both carriageways stop and a single lane numbering is used again with the ETSI LanePosition 1-3 and 14 for the hard shoulder.

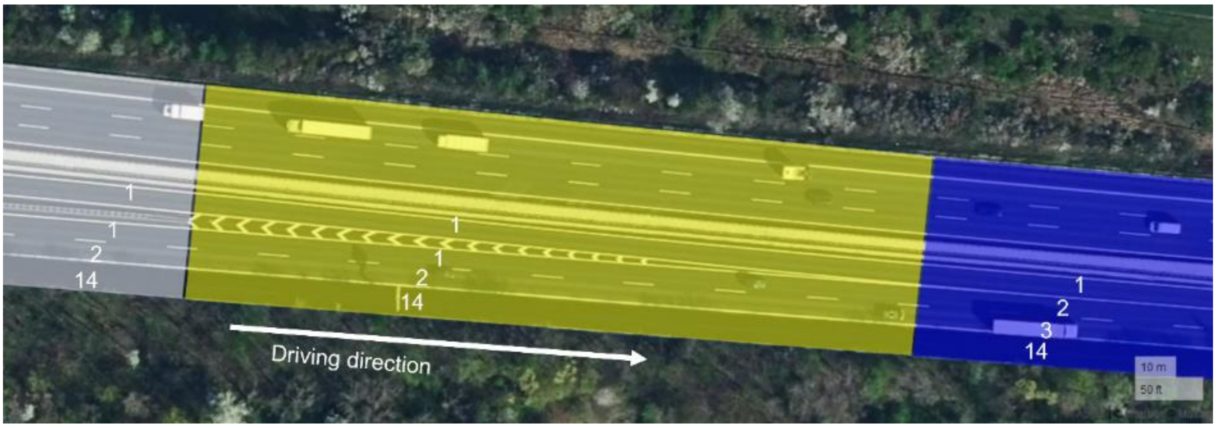

Figure 31: ADASIS-road segments for the scenario in clause 3.2 (where the lanes merge) with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Similar scenarios

The scenario of clause 3.2 can exist in a variety of versions. A general schematic is shown in Figure 32 and could also represent the situation shown in Figure 6, where one driving lane is separated from others by a (permanent) concrete wall. The transformation algorithm in clause 4.3.3 ensures that the single, separated lane and the two lanes + hard shoulder use independent lane numbering scheme. The single lane becomes ETSI LanePosition 1, because it is guarded by a central reservation and a wall (see step 3). The other lanes are guarded by a wall and the road border. Again, according to step 3, those lanes are treated as individual carriageway and become ETSI LanePosition 1 and 2 for the regular driving lanes and ETSI LanePosition 14 for the hard shoulder.

This example is also a case where step 3.c can be relevant. Let’s assume the ego vehicle is located on inner carriageway with the single lane. Furthermore, the width of this lane is part of the ego’s map data. If the ego would derive the lane information only from an absolute position, but the (lateral) accuracy is bad (e.g., 3 m), the ego cannot reliably determine if it is one the inner or outer carriageway. With this uncertainty, the ego vehicle should not provide lane information. If the ego vehicle would use camera-based image processing instead, it could be able to determine its carriageway and could provide lane information.

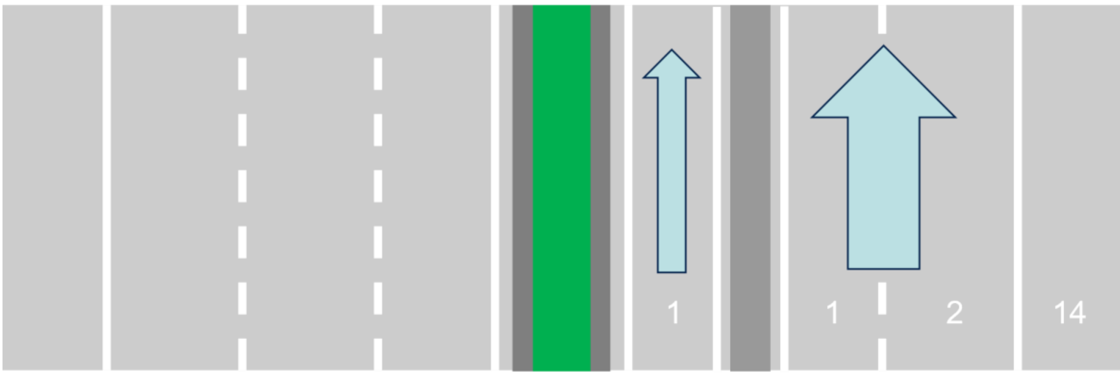

Figure 32: Schematic representation of the scenario in clause 3.2 with the expected **ETSI** LanePosition for one driving direction.

4.4.3 Complex motorway junction

For the complex motorway junction of clause 3.3, the same approach as for clause 4.4.1 is used to focus on some parts and not describe all carriageways and directions in detail. Only the following parts of the junction are described in detail:

- Bridge ‘Muiderbrug’
- Central crossing
- Eastern End

Bridge ‘Muiderbrug’

The bridge is directly connected to the western end of Figure 7 and Figure 8. The section of the motorway is shown in Figure 33.

The bridge itself consists of the carriageways for the motorway (shown in red) and an additional one-way road (Maxisweg). The Maxisway allows a traffic flow in the opposite direction compared to the adjacent motorway direction. However, the one-way road is an independent road and is separated from the motorway. As a result, both roads have an individual lane numbering scheme and the Maxisway does not have to be considered for the lane numbering scheme in this example.

As described in clause 3.3, there is a reversible lane in between the different directions. This lane can follow the depicted driving direction in Figure 33, but it can be also the opposite. Thus, the lane should be (physically) separated to both driving directions of the motorway. This dynamic usage of such lanes is a challenge today. ADASIS provides mainly static data about the road network (e.g. that this lane can be used by both directions), but it cannot provide the applicable driving direction for such lanes at a certain moment in time. Future versions incorporating IVIM information or other dynamic content maybe solve the issue. Nevertheless, (physically) separated lanes would result in an individual lane numbering anyway (see step 3 in clause 4.3.3). Regardless of the used direction, the main carriageway following the same direction is counted individually.

Assuming the driving direction East to West in Figure 33, motorway is represented by the blue and red segment. Both segments consist of four normal driving lanes, no hard shoulder lane is present. This results in the depicted lane numbering, where the innermost driving lane becomes ETSI LanePosition 1 and the number increases to the outside, with the outermost driving lane of the motorway as ETSI LanePosition 4. As said, the Maxisway does not belong to the motorway.

The border of the red segments is the point where the carriageways split and do no longer run strictly in parallel (see also Figure 8 or Figure 35) until they merge again. This changed run of the road makes a segmentation difficult to depict and view, where both directions are considered (as done before). Instead, each carriageway of this example within the area is segmented individually unless otherwise noted.

Even if ADASIS would model this part as a single entity, no error is introduced with respect to the lane numbering scheme by individual segmentation as done here. The general approach of clause 4.3.3 considers only the lanes for the vehicle’s driving direction for the lane numbering scheme. The lane numbering scheme is applied per segment and different, subsequent segments maybe use an identical number of lanes and an identical lane numbering scheme. Only if the number of lanes in the considered driving direction changes, the lane numbering scheme is affected. Changes on the carriageway for the opposite direction create additional segments, but nothing changes on the lanes for the current driving direction. There would be two subsequent segments with identical properties. Figure 24 is such an example when a vehicle would follow the opposite driving direction than the shown one. Regardless of all changes, all segments in the opposite direction than the shown one consist of five lanes. No addition or remove of lane(s) on the opposite carriageway, affects the considered carriageway. Therefore, it is valid to split the segmentation in this example as well.

Figure 33: ADASIS-road segments for the 'Muiderbrug' of scenario in clause 3.3 (where the exit lane starts) with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Central crossing

The 'central crossing' is the part of the junction, where the motorway A9 (towards south-west) diverges from / merges with the motorway A1 (east to west). The depicted segments in Figure 35 covers the reversible carriageway in between in the regular motorway carriageways (adjacent red and green segments). This is done to demonstrate, that the principles are also applicable for such ways, assuming that a defined driving direction is known. Whether or not vehicles can use the carriageway in this direction at a certain point in time, is not available to ADASIS and has to be identified by other means.

The assumed driving direction for this case is east to west. The original ADASIS lane numbering is shown in Figure 34.

Figure 34: ADASIS-road segments and **ADASIS** lane numbering for the central crossing of scenario in clause 3.3 (where the motorways crosses each other). (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

For the imaginary ego vehicle, the initial segment is the white one with 3 regular driving lanes, no hard shoulder. The lanes are separated by dashed lane markings of two different types, but they do not change within this segment. The innermost driving lane (according to the assumed driving direction) is southern lane and becomes ETSI LanePosition 1. The middle lane becomes ETSI LanePosition 2 and the outermost lane (northern lane) becomes ETSI LanePosition 3. The changed lane marking from the dashed line to a solid line result in the new segment (grey). As before, a simple solid line is not considered as separator to split the carriageway. The number of lanes is unchanged and the same lane numbering scheme as in the white segments applies. However, it shall be noted, that the two northern lanes of the grey segment are not reversible, they can be used only for driving 'east to west' (see also the arrows on the lane). At the end of the grey segment, the road splits into a small white segment with two lanes (merging together into a single lane leading to the small red segment at the border; also exclusively used for one driving direction and not reversible) and a yellow segment with just one, reversible lane. Traffic following the small white segment merges with the regular, northern carriageway, while traffic following the yellow segment stays on this carriageway with reversible lanes. Both parts are separate by a white shared, restricted area. The split starts as soon as this restricted area appears. For the new started segments another lane numbering scheme have to be used to reflect this change of the road layout. This approach is also in line with the approach in clause 4.4.1, where the exit lanes diverge from the motorway.

The yellow segment consist of a single lane and the lane becomes ETSI LanePosition 1. The right border (in direction of travel) is the restricted area and not counted at all.

The other part (the small white and red segment) starts with 2 lanes in the white segment. The leftmost lane is a closing lane and merges with the outer lane of the segment. This part is guarded on both sides. The white shaded, restricted area separates it from the yellow segment and guardrails on the other side separates this part from the regular motorway. Thus, this part is treated as individual part with an individual lane numbering scheme. Even if the leftmost lane in this segment is closing, the lane can be (partially) used by vehicles and have to be considered for the numbering. The closing (leftmost) lane becomes ETSI LanePosition 1, the outer lane (that continues) becomes ETSI LanePosition 2. This behaviour is in line with its opposite – see for example the opening lane in clause 4.4.1. The white segment connects to the red segment and the red segment consist of just a single lane (the closing lane disappeared). This single lane becomes ETSI LanePosition 1 and is guarded on both sides as well. Towards the left, a guard-rail separates the lane from the carriageway with the reversible lanes. Towards the right, a new restricted, white shaded area starts as separation to the regular driving lanes. As the red lane merges with the motorway, the white area becomes thinner and at the end of this restricted area, the red segment merges with the motorway and another segment starts.

As seen in the figure, the motorways cross each other via a bridge. The ADASIS data describes the road course via Polylines of WGS84 Positions, including altitude information. Furthermore, the data attached to the road contains information were a bridge starts and ends. If a vehicle receives a CAM of another vehicle moving on the crossing carriageway (bridge), the receiver can use the position (which includes altitude) and headings to map the remote vehicle onto its own road data. Using the additional information of the related road-part (e.g. if it is located on a bridge), the receiver can distinguish between relevant vehicle and non-relevant vehicles on another (crossing) carriageway, e.g. on a bridge above its own carriageway.

Figure 35: ADASIS-road segments for the central crossing of scenario in clause 3.3 (where the motorways crosses each other) with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

In Figure 36 the results are shown if the opposite driving direction would be used. The general road and lane layout are independent of the driving direction. With an unchanged lane layout, the same segments exist and only the lane numbering differs. The numbering is not a plain invert of the other side, it has a special case for the opposite direction.

Starting at the left border of the figure, only the yellow segment is an entrance from for the direction 'west to east'. Only this single lane is reversible and becomes ETSI LanePosition 1. The red and white segment in parallel are exit lanes that merge with the 'regular' motorway. They are not reversible. As a result, also the grey segment has 'one way' lanes and a reversible lane. For the considered driving direction, only the most southern lane is reversible, can be used in the direction 'west to east' and has to be considered for the lane numbering (ETSI LanePosition 1 is assigned to this lane). The two other lanes of the grey segment are exclusive for the opposite direction and are not counted in this case. In contrast to the other case before, the solid lane marking between them is not just a separation of the lanes, it is a separation of the driving directions. When entering the white segment, all lanes are reversible and have to be numbered. The northern lane becomes ETSI LanePosition 1, the middle lane becomes ETSI LanePosition 2 and the southern lane becomes ETSI LanePosition 3.

Figure 36: ADASIS-road segments for the central crossing of scenario in clause 3.3 (where the motorways crosses each other) with the expected **ETSI** LanePositions for the opposite direction. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Eastern End

Figure 37 shows the eastern end of Figure 7 and Figure 8. It consists of the following carriageways (in order from top to down):

- A part of the Maxisweg (upper right corner, without overlay)
- A sideway of the motorway with a single lane and a hard shoulder lane (yellow overlay)
- *A connection between the sideway and the motorway (A9) with a single lane and a hard shoulder lane (black overlay) – Part I*
- *The part of the motorway that splits from the A1 and continues as A9 with 3 regular lanes and a hard shoulder (red overlay) – Part II*
- *The part of the motorway that splits from the A1 and continues as A1 with 3 regular lanes and later also a hard shoulder lane (blue and black overlay) – Part III*
- The carriageway in between the different driving directions with 2 reversible lanes (red overlay)
- The carriageway for the opposite driving direction where the parts from A1 (3 regular lanes, black overlay) and A9 (3 lanes and hard shoulder, blue overlay) merge into A1 (white overlay)
- A sideway of the motorway with 2 regular lanes and a hard shoulder lane (white overlay)
- *The yellow overlay at the right border (yellow overlay) represents the area where all carriageways continue in parallel and are considered again as a single road segment. – Part IV*

The italic points are described more in detail. They belong to the considered driving direction of Figure 37 and are also labelled in the image.

The shown part I is an independent one-way carriageway with the road border as border on both sides. Later, part I merges with part II (not shown in the figure; separated by a restricted, white area before merging). As the shown part I is separated to part II, it maintains an individual lane numbering scheme. The regular driving lane becomes ETSI LanePosition 1 and the hard shoulder lane becomes ETSI LanePosition 14.

Part II and part III diverge from part IV. Part II is separated to part III with a restricted, white area. Like in clause 4.4.1 and 4.4.2, the start of the such an area is used as indication to start a new lane numbering schemes for the new independent parts. The red segment of part II consists of 3 regular driving lanes and the hard shoulder from part IV continues in this part. The innermost (leftmost) lane in the direction of travel becomes ETSI LanePosition 1, the outermost (rightmost) regular driving lanes becomes ETSI LanePosition 3. The hard shoulder becomes ETSI LanePosition 14. When the red segment changes to the yellow segment (upper left corner of the figure), the hard shoulder ends and is replaced by a restricted, white area that is not counted (later, part I merges with part II). As a result, the yellow segment takes over the lane numbering from the red segment, excluding ETSI LanePosition 14.

Part III starts with the blue segment and with an individual lane numbering scheme (as result of the split, indicated by the restricted, white area). The blue segment has 3 regular driving lanes and no hard shoulder lane. Therefore, the innermost (leftmost) regular driving lane becomes ETSI LanePosition 1, the outermost (rightmost) regular driving lanes becomes ETSI LanePosition 3. The blue segment ends with the restricted, white area. The following black segment has the same regular driving lanes as the blue one (and numbers the lanes in the same way as before) but with an additional hard shoulder at the outer side. The new hard shoulder becomes ETSI LanePosition 14.

Part IV is represented by the large yellow segment. Like in clause 4.4.1, the opposite driving direction is not considered for the lane numbering. The carriageway with the reversible lanes in between the two major carriageways is also an independent carriageway. This smaller carriageway is separated to the others by guard-rails and according to step 3 in clause 4.3.3, this results in an independent lane numbering scheme for this carriageway. The remaining piece consists of 6 regular driving lanes and a hard shoulder lane following the depicted driving direction. The hard shoulder is located at the outside (rightmost) border of the carriageway and becomes ETSI LanePosition 14. The innermost regular driving lane becomes ETSI LanePosition 1 and each lane further to the outside receive a higher lane number than the lane before – making the outermost regular driving lane ETSI LanePosition 6.

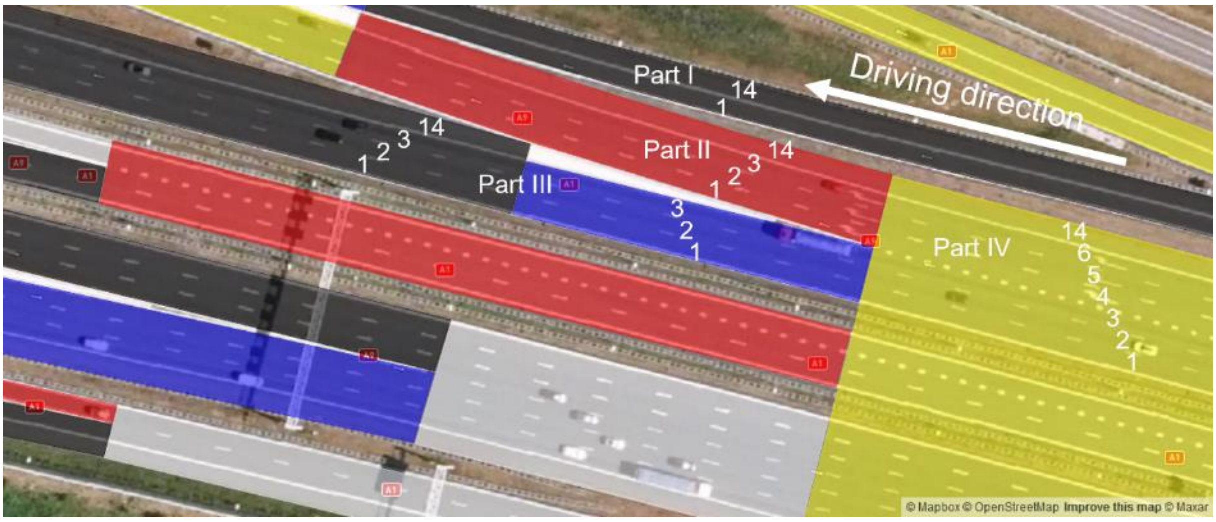

Figure 37: ADASIS-road segments for the eastern end of scenario in clause 3.3 (where the exit lane starts) with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

4.4.4 Rural road

Following the road in Figure 38 in the shown driving direction leads to two road segments. The initial blue segment covers the part of the road where each driving direction has a single lane available. In the yellow segment a new lane starts, which is a change of the connectivity, compared to the blue segment. This new lane is placed in the middle of the road, in between the existing lanes. Furthermore, the lane marking between the different driving direction changes from a single solid line to a double solid line (changed lane boundary as well).

According to the numbering scheme, lanes are counted per carriageway and per driving direction. This example has only a single carriageway, used by both directions. In contrast to the motorway scenarios, the directions are not separated by a central reservation, only by a single solid line or double solid line. According to the German law, this type of line is the legal (and optical visible) separation between the directions on those roads. In line with the definition of ETSI LanePosition (see [RD-2], A.40 DE_LanePosition), the lanes on this road are counted from the innermost lanes (the lanes closest to the solid line) to the outside. In the blue segment both lanes become ETSI LanePosition 1, because there is only one lane per direction. In the yellow segment, the new lane becomes ETSI LanePosition 1 because it is now the innermost lane and the exiting lane changes from ETSI LanePosition 1 to 2.

Figure 38: ADASIS-road segments for the scenario in clause 3.4 with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

This scenario is also a good example for comparing ETSI LanePositions across segments by a receiver. Let's assume a vehicle is driving in the blue segment, following the depicted driving direction in Figure 38. If the vehicle receives a DENM for an event in the yellow segment that is located on the outermost lane (with ETSI LanePosition 2), a plain comparison of the ETSI LanePosition could be misleading. The vehicle in the blue segment cannot just assume that the event is located on a different lane, because just the ETSI LanePositions are different. Instead, in the real world, the event is located on the same lane and following the lane from the blue to the yellow segment would bring vehicles directly to the event. This can be avoided by considering segment changes and evaluate the connections between segments. Luckily, ADASIS provides the necessary connection information.

4.4.5 2+1 road

On 2+1 roads the usage of the middle lane alternates. For several kilometers the lane is used by traffic in one direction, for another part the lane is used for the traffic of the opposite direction. For some stretches, the road could also shrink to just 2 lanes. Basically, this type of road can be reduced to:

- A new lane added to the left of the current lane (when a part starts), and
- the centre lane closes (when the part ends)

This dynamic has to be addressed by the lane counting scheme. Considering the selected example of clause 3.5, those two types lead to Figure 39 and Figure 40.

In Figure 39, the red segment contains two regular driving lanes, whereby the middle lane can be used in the shown direction of travel. The middle lane is the innermost (left) lane and becomes ETSI LanePosition 1. The outer lane becomes ETSI LanePosition 2. In the blue segment, the innermost (middle) lane closes and merges with the outer lane. Like in Figure 24, this part of the road with an opening or closing lane is described as independent segment. Since there are no other changes compared to the red segment before, the same lane numbering applies. In the final green segment, only one lane is available per direction which becomes ETSI LanePosition 1.

Another possible layout of the situation in Figure 39 is also shown in Figure 10, where the driving directions are separated by a white shaded, restricted area. Such an area would be a type of lane marking and not a driving lane. As a result, those areas would be not considered for the counting at all, they just add a safety margin.

Figure 40 shows the same situation as already described for the rural road in Figure 38. The figure is not explained again.

It shall be noted that the separation between the driving direction can be either a line marking or a physical separator, like guardrails or some types of fences. The transformation algorithm in clause 4.3.3 is based on the ADASIS data and the lane-direction-properties. The algorithm is independent of the optical separation on such roads and can deal with both.

Figure 39: ADASIS-road segments for the scenario in clause 3.5 with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

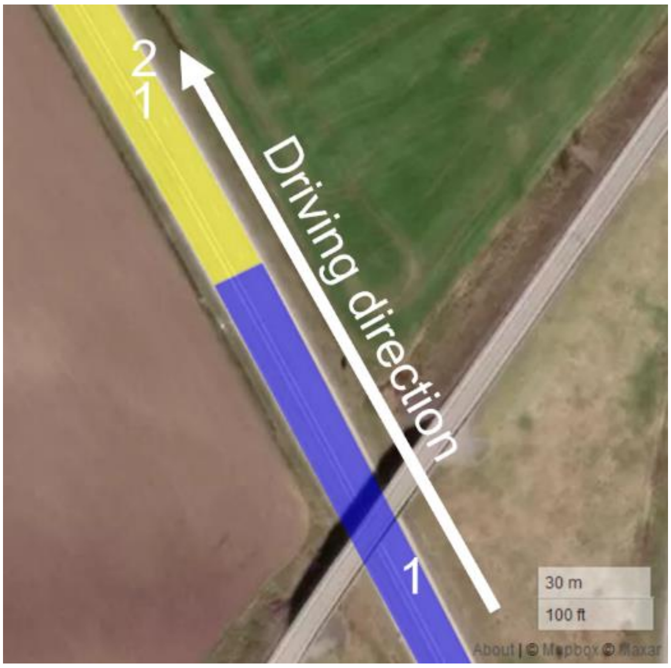

Figure 40: ADASIS-road segments for the scenario in clause 3.5 with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

4.4.6 2-1 road

In comparison to the previous examples, the 2-1 road has just a single lane for both driving direction. As a result, this type has no legal separation of the driving directions (like a solid line in the middle). Both directions share the same lane. This lane is not a reversible lane (where vehicles of a driving direction can use the lane exclusively), it is just a normal lane where both driving directions are allowed. The lack of a legal separation has to be addressed. In this case, the innermost border (lane marking) of the innermost lane should be considered as legal separation. By doing so, both directions have a clear guidance for the lane numbering scheme, which makes the central lane as ETSI LanePosition 1 for both directions. This is in line with the transformation algorithm step 2, where all lanes following the ego's driving direction are selected. The centre lane fulfils this criterion for both directions.

The sidewalks for pedestrians, bicycles and alike are directly attached to the central lane (they are on the same carriageway) and just separated by a (dashed line) lane marking, but no physical structure (like a kerb). In case of a 2-1 road, the lane numbering scheme can include the sidewalks, so they become 'an additional driving lane' with ETSI LanePosition 2 (in case that vehicle meet one another).

In Figure 41, the blue segment is the 2-1 road with the ETSI LanePositions for the shown driving direction. The green segment is the transition from the 2-1 road into the area of a small town. The traffic island in the green segment does not affect the lane numbering, it divides the different driving directions. Each side of the island carries traffic of only one direction so no special handling is required for this island.

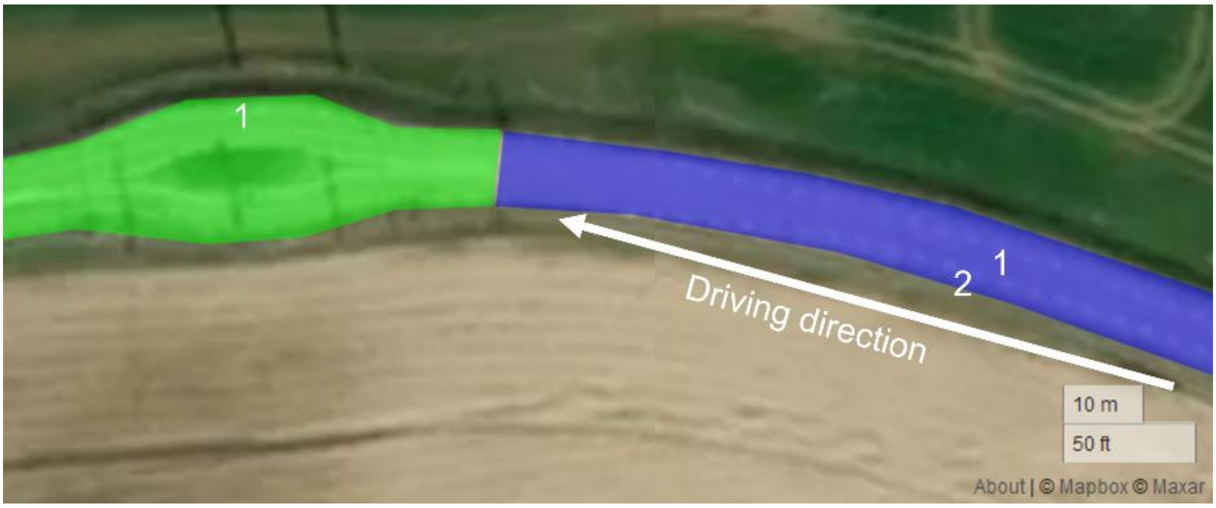

Figure 41: ADASIS-road segments for the scenario in clause 3.6 with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Another relevant point affects the lane change of a vehicle. This is especially relevant for 2-1 roads but applies also to all other types of roads. Today, the ETSI messages, like CAM [RD-18], define that a vehicle can only put a single ETSI LanePosition into a message. This becomes problematic for lane change manoeuvres. During a lane change, it is not defined how long a vehicle belongs to the original lane and when it belongs to the new lane. There are no criteria like ‘the lane where ⅔ of the vehicle are located in’ or similar. But even with such criteria a part of the vehicle still occupies the other lane. Alternatively, future ETSI message or revisions of existing message could support more than one lane. This work is open and should be addressed in Car2Car to prepare a contribution to ETSI.

4.4.7 3-lane road

On a 3-lane road, the centre lane can be used by both traffic directions (at least partially). Therefore, vehicles on that lane should be able to provide lane information when they use this lane. In terms of the ADASIS lane numbering scheme, the counting is not an issue. They start with the outermost lane in the direction of travel and count all lanes towards the other border of the road, see Figure 42 for an example.

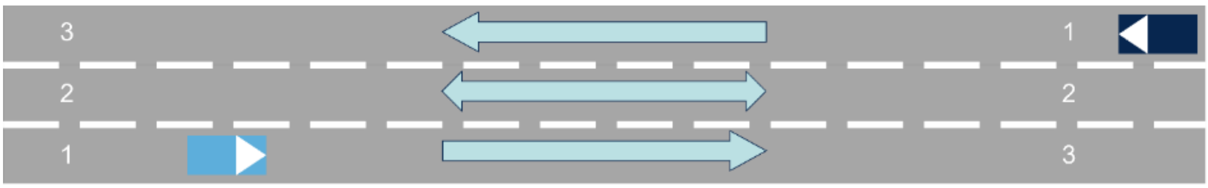

Figure 42: A 3-lane road with the **ADASIS** lane numbering. The left numbers are the ADASIS lane number for vehicles traveling from left to right. The right numbers are the ADASIS lane numbers for vehicles travelling from right to left.

Considering the ETSI LanePosition as target scheme, the situation is a bit different. As of today, in [RD-2] for the element LanePosition is written that:

‘*If the carriageway allows traffic in both directions and there is no physical delimitation between traffic directions (e.g. on a single carriageway road), the position is counted from the legal (i.e. optical) separation between traffic directions (horizontal marking).*’

This sentence is fully applicable to this scenario, but the road of this scenario has no legal / optical separation of the traffic directions. For a possible solution, it has to be considered that the ETSI LanePosition is counted from the innermost lane to the outside of the road. A lane to the left (in right-hand traffic) of the innermost lane cannot be described with this element.

To use the element ETSI LanePosition, the shared centre lane can be defined as innermost lane, i.e., the lane has to become ETSI LanePosition 1. The exclusive lanes per driving direction would become ETSI LanePosition 2, see Figure 43. The optical / legal separation would be defined as the lane marking between the shared lane and the exclusive lane for the opposite direction. This approach is in line with the transformation algorithm in clause 4.3.3 and addressed in step 2.

As shown in the figure, the centre lane is ETSI LanePosition 1 for both directions. For those scenarios, the receivers should definitively use their map data to know that the centre lane can be used by both directions and to assess the situation correctly for vehicles on the centre lane.

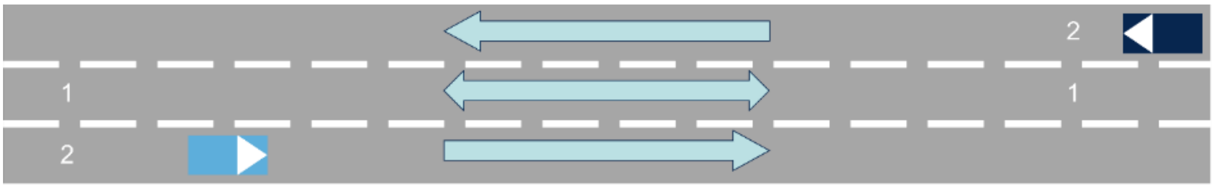

Figure 43: A 3-lane road with the expected **ETSI** LanePositions. The left numbers are the ETSI LanePositions for vehicles traveling from left to right. The right numbers are the ETSI LanePositions for vehicles travelling from right to left.

4.4.8 Urban Intersection

An intersection is a place where roads cross each other, allowing a vehicle to either follow the original road (if this road continues) or change to another road. As vehicles can follow multiple paths, each path should be described in detail in the following. But first, the common approach to the intersection is described.

For this example, vehicles enter Figure 44 at the left border in the blue segment. This segment has 2 lanes, the innermost lane is ETSI LanePosition 1, the outer lane is ETSI LanePosition 2. The green strip separates the driving directions. The strip would only have to be handled in a special way, if it would separate lanes following the same driving direction – which is not the case in this example. In the green segment, the carriageway is extended by 2 lanes, one to the left and one to the right of the existing lanes. Those new lanes affect the lane numbering scheme and results in new numbers for the existing lanes. The former lane with ETSI LanePosition 1 becomes ETSI LanePosition 2 and the former ETSI LanePosition 2 becomes ETSI LanePoistion 3. The new innermost lane become ETSI LanePosition 1 and the new outermost lane becomes ETSI LanePosition 4. As soon as the new lanes are fully open, the red segment starts and ends with the stop line right before the conflict zone of the intersection. The lane numbering of the green segment is taken over for the red segment.

Figure 44: ADASIS-road segments for the scenario in clause 3.7 with the expected **ETSI** LanePositions for vehicles crossing the intersection straight. The solid line across the intersection is the more general path to follow. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Path ‘straight’

Figure 44 already shows the ADASIS segments and the expected ETSI LaneNumbers for the straight manoeuvre. The stop lines are the borders of the conflict zone and located directly at the end of the red segment. The conflict zone is the area where the three paths across the intersection split.

The ‘straight’ path is subdivided into two segments. The first segment, the grey one, is the initial segment with a solid line on the left border as separation to the left turn lane that extends a little bit into the conflict zone (the stop line for the left turn lane is located right before the lorry). When the lane border changes from a solid to a dashed line, the blue segment begins and covers the rest of the conflict zone before the white segment starts that represents the egress approach of the intersection. The grey and blue segment consist of two lanes, whereby the inner lane becomes ETSI LanePosition 1 and the outer lane becomes ETSI LanePosition 2. The same scheme applies to the white segment that consists of two lanes for the given driving direction.

For the grey segment, with the lanes of the ‘straight’ path running in parallel to the left turn lane, the ADASIS specification is not clear if the left turn lane is treated as individual path or still belong to the ‘straight’ path. If the left turn lane would be considered as part of the ‘straight’ path, the grey segment would consist of three lanes instead of two. Figure 44 shows the version with the left turn lane as individual path.

Path ‘turn right’

For turning right, the white path in Figure 45 diverges from the blue path. This path consists of the right turning lane for the considered driving direction and the left turning lane for vehicle coming from the lower border of the figure (opposite driving direction).

For the right turning lane, only a single segment is necessary to cover the conflict zone (blue). There is only one ingress and one egress lane for this direction and there are no changes within the conflict zone. For the opposite direction, the path consists of the blue segment as well but also includes the green and grey segment because of the changed lane boundaries (from no boundaries to dashed lines to solid lines). After leaving the conflict zone following the direction of travel, the lane connectivity (on the part of the opposite direction) and the lane boundaries change (from dashed line at one side to solid lane marking at both sides), which is reflected by the red segment. Both segments, the blue and the red one consist of a single lane and thus those lanes become ETSI LanePosition 1. As before, the opposite driving direction (i.e. the left turning lane when coming from the lower border) is not considered for the lane numbering.

Figure 45: ADASIS-road segments for the scenario in clause 3.7 with the expected **ETSI** LanePositions for vehicles turning right. The solid line white line diverging from the blue one is the more general path to follow. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Path 'turn left'

The left turn manoeuvre is indicated by the black path in Figure 46 that diverges from the blue path. The left turn lane extends a bit into the intersection, it does not stop at the same level as the straight lanes or right turn lane.

The left turn path consists of a grey segment, which represents the original left turn lane before entering the conflict zone and the blue segment in the conflict zone. After leaving the conflict zone, the green segment represents the egress lane of the intersection. Like in the right turn manoeuvre, the egress lane forms a new segment due to changed lane boundaries. Both segments, the grey and the blue one consists of a single lane and thus they become ETSI LanePosition 1. As before, the opposite driving direction (i.e. the right turning lane when coming from the upper border) is not considered for the lane numbering.

Figure 46: ADASIS-road segments for the scenario in clause 3.7 with the expected **ETSI** LanePositions for vehicles turning left. The solid line white line diverging from the blue one is the more general path to follow. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

Summary for intersections

The above examples considered only a single intersection and only a single approach of this intersection. Based on the example, the general principle for lane numbering could be also applicable to intersection, but maybe other intersections are more challenging for the lane numbering within the conflict zone than the shown one. As seen from the example, the ingress approach split from 4 lanes into multiple small connections with 1 or 2 lanes, each connection with its own lane numbering. This behaviour is identical for all the other ingress approaches, they all split into multiple smaller lane-sets. If all connections of all approaches are placed one over another, a lot of connections with 1 or 2 lanes exists. As a result, all vehicles using those connections would put ETSI LanePosition 1 or 2 into their CAMs. Having only ETSI LanePosition 1 or 2 in the conflict zone is maybe not helpful for receivers. They need an explicit and reliable (and fast) mapping of other vehicles (i.e., CAMs) to their map database. This mapping can be challenging considering various position confidence intervals and jitters in all absolute positions, which are the base for such a mapping. It could be hard for a receiver to decide on which lane another vehicle is according to its internal data, especially when there are multiple lanes in parallel or an ingress lane connects to multiple egress lanes.

An alternative to the approach above is the use of MAPEM information (see [RD-19]) where available. MAPEMs describe the intersection layout, with ingress and egress lanes as well as the existing connections between the ingress and egress lanes. All lanes and connections have a unique identifier within the intersection. For the general use of SPATEM and MAPEM information, vehicles close to the intersection have to map themselves anyway onto a lane described in a MAPEM. If the ingress lane mapping is known for a vehicle, only a limited number of connections is possible starting from this lane. Together with additional information (e.g., a known route or active turn indicators), the vehicle can already know the connection to use before entering the conflict zone. When entering the conflict zone, this information just has to be broadcasted. To enable such a broadcast, CAMs have to support the connection-Id (together with the Id of the related MAPEM) beside the ETSI LanePosition. This allows all vehicles close to or within the intersection (i.e. conflict zone) to know very precisely which vehicles are using which connection and which of them are relevant for the ego vehicle. The same principle can be applied to events (DENMs) detected in the conflict zone. Using the connection’s Id for vehicle or events in the conflict zone, the receiver can make a clear relevance assessment and decide how to react on such events, see also Figure 47. Issues with unprecise absolute position information can be reduced. Additionally, this could also ease the workflow of roadside equipment, monitoring the intersection. If they detect a conflict or hazard, the Roadside unit is already aware of the affected connection(s). Instead of just broadcasting this information, today, the RSU would have to transform the event location into an absolute position, to let receiving vehicles transform it back from an absolute position into an affected lane.

In brief: Information within the conflict zone should be made available using the related connectionId e.g. using the CDD (see [RD-2]) data field MapPosition instead of LanePosition (which should be absent in this case). Vehicles approaching the conflict zone or that have already left the conflict zone should use the lane numbering scheme defined in this white paper and can additionally use the component laneId of data field MapPosition (if still in the area defined by the MAPEM) in order to facilitate the hand-over between the MAP based and the LanePosition based approaches.

This alternative approach for lane numbering using data field MapPosition within the conflict zone seems to be superior to the ETSI LanePosition available today. This switch between connectionId and ETSI LanePosition can be made explicitly visible via the presence of different data elements in the corresponding ASN.1 message definition as suggested above.

Figure 47: Example for a conflict within the conflict zone that can be addressed precisely by using the connection's Id (connection 2 and 3) instead of absolute lane numbering. Connection-Ids 2 and 3 are unique within the conflict zone and all receivers can evaluate quickly if they cross or came close to those connections or not. (Provided by Yunex GmbH in the scope of C2C-CC’s WorkItem D0025)

4.4.9 Roundabout

The ingress and egress lanes of the roundabout are just normal roads. Inside the roundabout, whenever the lane markings change from a dashed line to a solid lane or to a restricted area, a new segment has to be used. Right before entering the roundabout, the ingress lane is separated from the egress lane by a sealed area, probably concrete or cobble, with a curb as road border. This is also a change in the lane boundaries and thus a new segment has to be used. All those segments consist of one lane per driving direction and all of the lanes become ETSI LanePosition 1, see Figure 48.

Within the roundabout, there are two types of segments. All the white segments have solid white lines as borders. The other coloured segments have a solid white line as inner border and a dashed white line as outer border, where vehicles enter or leave the roundabout. The parts for entering and leaving the roundabout are separated from each other, because the connectivity changes between them. The roundabout lane has an exit and a connection to the next segment and the next segment has an entry that merges with the roundabout-lane. Regardless of this split and the different lane boundaries, the entire roundabout consist of segments with just a single lane and all those lanes are assigned ETSI LanePosition 1.

The large number of small segments within the roundabout results from strictly applying the ADASIS rules (see clause 4.3.1) onto this example. The segments itself are not part of CAMs or DENMs, only the resulting ETSI LanePosition is. This number of segments have to be handled by the in-vehicle systems but has no impact on the amount of shared data.

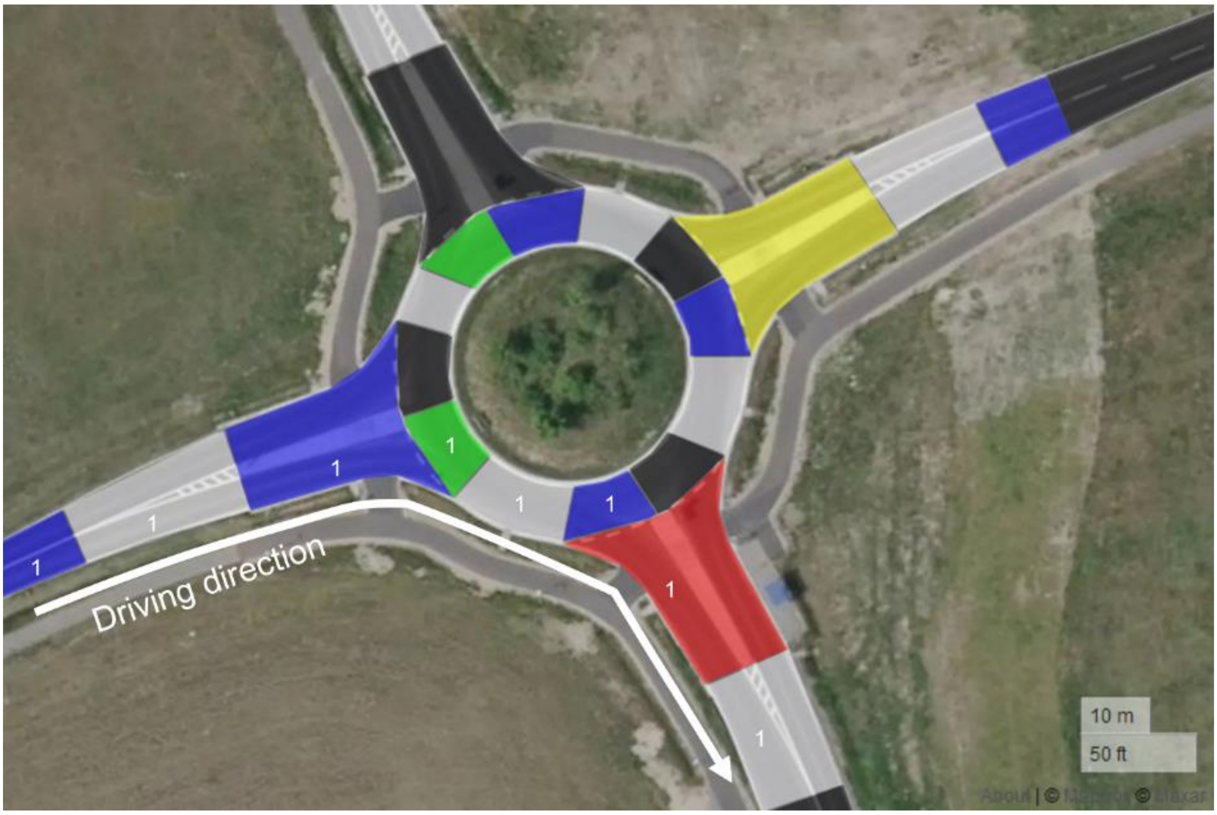

Figure 48: ADASIS-road segments for the scenario in clause 3.9 with the expected **ETSI** LanePositions. (Source: created using https://geojson.io © Mapbox (see: https://www.mapbox.com/about/maps/) © Maxar (see: https://www.maxar.com/))

With regards to roundabouts with more than one lane: While the current version of the White paper does not contain an example for them, the same procedure applies to them as for the single lane roundabout. The roundabout is split into segments with equal number of lanes and the ETSI LanePosition is derived from the related segment where a vehicle is driving.

5 Open Points and future work

The previous chapter described the expectations for various scenarios. Several situations can already be addressed based on the ADASIS guidelines and the proposed conversion algorithm, but also some unsolved issues arose:

- As described in clause 4.4.6, ETSI nor C2CCC define rules for the lane number to use for vehicles that is changing lanes, driving in between lanes, or (legally or illegally) driving in the wrong direction. Furthermore, ETSI cannot provide information if more than one lane is occupied by a vehicle.

- Clause 4.4.7 shows the application of the guidelines to the conflict zone of an intersection and the resulting complications for the receivers. Probably, the connectionId, referenced to a MAPEM, provides more benefit for a receiver. ETSI CDD does support such an option already, but it is not yet available in the CAM/DENM: this could change during the work for the ETSI ITS Release 2.

- Another unsolved situation is the handling of dynamic content, like the handling of changes in the general lane layout. Roadwork zones, both, short and long term, are a major cause of such changes. For example, on a motorway a roadworks zone can reroute the traffic of one direction onto the carriageway of the opposite direction with a temporary, physical separation of the driving directions. Currently, C-Roads is working on a handbook for C-ITS messages in different types of roadwork zones. Like this white paper, they describe various roadwork-related scenarios and the proper modelling of C-ITS messages. Once the handbook is available, there scenarios can be used as additional input to validate a future version of the lane numbering concept of this white paper for road work scenarios.

  Furthermore, various types of lane markings (especially coloured lines and marker lights buttons) exist in and around roadwork zones. While vehicles can run over some types of marker light buttons and other not, all those buttons are a type of lane marking to consider for the lane numbering rules. They provide guidance about the course of the lanes. The usage of a road zipper causes the same set of issues, where the new layout and lane usage have to be shared with the traffic participants and the changed layout have to be considered.

  Other situations with dynamic content are reversible traffic lanes that exist with several characteristics. Beside the example in clause 4.4.3, the Heerstraße in Berlin, Germany, is another one. Variable traffic signs are mounted above a single carriageway. The signs are visible for both direction and indicate which lanes can be used by which driving direction. While the ADASIS data can inform about the presence of a reversible lane, the data cannot provide information about the currently allowed driving direction.

  While the general ADASIS rules and the lane numbering of this white paper should be applicable to such changes, the primary issue is getting the new, real world lane layout and lane usage for such zone and sharing the data among the affected traffic participants. Today, both examples can be handled by human drivers, but automated or autonomous vehicles maybe need additional support to pass such areas. Future ETSI C-ITS release and deployments maybe provide proper solutions to share all the dynamic content.

- Because LanePosition information have not been used so far in vehicle CAMs or DENMs, there are no confidence requirements for the data element defined yet. Future version of C2C-CC’s Vehicle C-ITS station profile should define such requirements, but first an internal discussion shall conclude on confidence values and levels to achieve. Necessary test procedures maybe have to be discussed as well.

The open issues have to be addressed by future work and maybe require some effort to come to a proper conclusion. However, the issues do not prohibit the provision of ETSI LanePositions at all today or in the near future. There are a lot of situations where already today an ETSI LanePosition could be provided. The data element is still optional in all C-ITS messages and if vehicles face one of the open scenarios (and detect it), they can just omit the ETSI LanePosition information.

6 Conclusion

This white paper presented issues for a harmonized lane numbering on roads with a possible solution relying on the general approach used and defined by the ADASIS specification. The paper:

- provided a list of scenarios to address
- introduced and explained the ADASIS approach
- defined a way how the ADASIS data can be transformed into the required target format (ETSI LanePosition)
- validated the approach by applying the definitions onto the defined scenarios and described the expected results and reference for similar scenarios.

Based on the scenarios, it was shown that the ADASIS approach addresses the issues for a harmonized lane numbering. The approach is a feasible solution to provide lane number information – an information that is not provided by today's vehicles. The ADASIS projects has many different members from the automotive industry, manufacturers and suppliers, and map data providers. With the wide range of members, their specification should be aligned between all of them and can be considered as a type of industry-wide agreement.

6.1 Suggestions for C2C-CC BSP

With respect to the work done, this white paper suggests including the following requirements into future versions of the BSP (italic text; details still to be discussed in the regular change process of C2C-CC):

- '*The vehicle C-ITS station should add lane information to its generated CAMs on motorways and in non-urban environments.*' – The approach can address a lot of general scenarios, but this white paper also identified items to discuss more in detail. There are probably challenging scenarios left that were not discussed at all in this white paper. Especially urban areas have to be addressed, so implementation should have the option to turn the feature off for some time or to not implemented it at all.

  The triggering condition documents already contain the lanePosition attribute, so the DENM was omitted in the requirement proposal.

- '*If lane information should be provided by a C2C-CC release 1 vehicle, the updated description of the ETSI LanePosition in [RD-2] should be used.*' – The updated version does not change the existing definition of the ASN.1 element but provides clarifications and an improved description that have been developed in this working group and contributed to ETSI.

- '*The vehicle C-ITS station should not add lane information to its generated CAMs while being on an urban road. Urban roads are all roads within an area whose entrance and exit are guarded by town signs. Motorways in such areas are not considered as urban roads.*' – see above. The proposal for using the connection-Id is not yet discussed nor accepted in ETSI.

- '*The lane information should be provided with regards to the lane layout of the road segment at the related reference position.*' – The related reference position is either the ego-position in CAMs or the eventPosition in DENMs. The BSP maybe attach this item to another, existing requirement but it should be added to avoid misinterpretation for which position the data should be created.

- '*The road segments should be determined according to the ADASIS approach as defined in [RD-15], clause 3.4.5.10:*

  'An ADASIS v3 Horizon Provider shall start a new Lane Model entry when the number of lanes or a lane property changes. A road segment is cut and a new Lane Model entry is started in the following situations:

  - *Lane connectivity changes, e.g., at an intersection, when a lane starts anew or a lane starts forming or a lane ends or a lane ends merging into another lane.*
  - *Physical divider or lane boundary between lanes starts or ends.*
  - *One of the lane boundary types changes.'*

  Note: An 'ADASIS v3 Horizon Provider' is the component that translates the underlying map data into the ADASIS format and broadcast it via in-vehicle networks to other components. A 'Lane Model' is the ADASIS representation of a lane with various attributes.'

  – This is the ruleset used in this white paper and whose applicability was validated. Basically, a segment changes, when the lane boundaries (lane markings and physical separators) or the connectivity between lanes change.
- '*The lane information for a position in the corresponding road segment should be derived from the ADASIS data according to the following transformation algorithm:*

  1. *Select the segment where the ego vehicle is currently driving on, by mapping the ego/reference position contained in the C-ITS Message (CAM, DENM, etc.) to the ADASIS map. Exit here, if the semi-major axis length of the actual positioning accuracy ellipsis (at 95%) is greater than 3 meters.*
  2. *Select all lanes of this segment that follows the ego's driving direction*[6]
     a. *Note: this includes lanes exclusively used by one direction as well as lanes that are shared / used together with the opposite driving direction*
  3. *If the segment has LinearObjects of type 'fence', 'wall', 'guardrail', 'curb' or a LaneMarking of type 'shaded area' in between the selected lanes*[7]*: Select a subset that:*
     a. *contains the lane where the ego is driving on and*
     b. *contains all adjacent lanes between the two closest borders. Note: a border is: either the road boarder, the opposite driving direction or a 'fence', 'wall', 'guardrail', 'curb' or a LaneMarking of type 'shaded area'*
     c. *Continue with the selected subset of lanes. If the lane is derived directly from an absolute position and the subset consists of only one lane whose width is less than the actual lateral positioning accuracy (at 95 %), then exit (i.e., no lane information can be provided).*

[6] Lanes in ADASIS have an attribute for the driving direction relative to the ego.

[7] LinearObject is an ADASIS type to describe elements running in parallel to a lane.

4. *If the lane with the lowest ADASIS lane number is of type 'RestrictedForbidden' or 'DrivableShoulder', assign ETSI LanePosition 14 to it*[8]

5. *If the lane with the highest ADASISI lane number is of type 'RestrictedForbidden' or 'DrivableShoulder', assign ETSI LanePosition 0 to it*

6. *Initialize a counter ETSICounter with 1*

7. *For all remaining lanes without an ETSI LanePosition:*

    a. *Take the lane with the highest ADASIS lane number that has not been processed yet; assign the value of ETSICounter as ETSI LanePosition to it*

    b. *Increment ETSICounter; Repeat step 7 for all remaining lanes*

8. *(Store association LaneNumber <-> ETSI LanePosition for future retrieval)*'

– The algorithm description is 'human readable' and should be usable even if no ADASIS data are available (for example where the detection is based on vehicle-camera only or the information is derived from an aerial image of a road). The expected outcome for the evaluated scenarios was created without access to ADASIS data but following this algorithm. To use the algorithm without ADASIS data, also the ADASIS counting scheme should be considered as define in [RD-15], clause 3.4.5.9.

Using this algorithm ensures that the same approach for splitting carriageways is used (like in clause 4.4.2).

- '*A vehicle C-ITS station that drives on a lane that is exclusively used by the opposite driving direction and ability to detect it should not add lane information to its generated CAMs (e.g., during overtaking or ghost driving).*' – The ETSI LanePosition element starts counting from the legal separation towards the outside for a given driving direction. There are no values for counting lanes of the opposite driving direction and the element cannot be extended without braking backward compatibility. As a result, the element cannot be used to provide useful information for a receiver and the element should be omitted. Such cases of overtaking or ghost driving could be addressed by an updated version of the CAM in release 2 that includes an additional element (e.g. a bit) to indicate the use of the opposite lane and / or by issuing a DENM. A corresponding DENM triggering conditions for overtaking and ghost driving would have to be defined by C2C-CC.

- '*A vehicle C-ITS station with access to map data should make use of those map data to interpret received lane information of other stations.*

  Note: Vehicle C-ITS stations without access to map data have to consider the unknown road situation where the road layout of the originator and receiver do not have to match.' – C2C-CC does not specify receiver requirements, but as described in the examples above, using map data is highly recommend for the interpretation of the shared data, see clauses 4.4.4, 4.4.6 and 4.4.8 for examples. By adding this statement,

[8] The working group assumes that a non-driveable hard shoulder lane is of type 'RestrictedForbidden' in ADASIS, but the ADASISI specification (see [RD-16]) did not contain a specific description for this today.

C2C-CC also emphasizes that it is open make use of map data in their current and future use cases for event detection and alike.

As this statement is more a guideline than a testable requirement, it should be added to the features-document ([RD-20]) instead of the BSP.

- <A requirement for the confidence is an open point and has to be discussed and developed. Intended to be added to this white paper in version 1.1.>
- *'Where on a carriageway with traffic for both directions no optical legal separation exists between the traffic directions:*
    - *If the total number of lanes N is even, the lanes are divided evenly between the traffic directions starting from the outside of the carriageway on both sides and the imaginary separation between traffic directions is on the border between the even number of lanes N/2.*
    - *If the total number of lanes N is odd, the lanes are divided evenly between traffic direction starting from the outside of the carriageway on both sides and the remaining middle lane is assigned to both traffic directions as innermost lane.*'

  – This is a clarification for the element LanePosition in [RD-2], as that case is not described there. Examples for such cases are 2-1 roads (see clause 4.4.6) or 3 lane roads with a centre lane that can be used by both traffic directions (see clause 4.4.7). This clarification is in line with the transformation algorithm step 2.

  C2C-CC should contribute this clarification to ETSI to extend the description of the element in the next update of [RD-2].

Taking over the above requirements into the BSP should enable future vehicles and road operators to provide lane information in CAMs and DENMs (or even IVIMs). With the reasoning given in clause 2, the proposed requirements of this white paper do not have an impact on backward compatibility for already operational equipment.

Finally, it should be emphasized that the work was done with a focus on motorized traffic driving on motorways and in non-urban areas. The results cannot be taken over directly to other types of road users in other areas, like pedestrians and variations of bicycles or e-scooters in urban areas. They do not have the necessary map information or are not equipped with cameras to detect their lane.

6.2 Suggestions for C-ROADS RSP

It is suggested that for the benefit of harmonization and interoperability, road operators use the segmentation approach according to ADASIS. Please note that this does not at all mean that road operators are forced to use ADADIS type maps.

6.3 Suggestions for Standardization

This white paper identified some open points or improvements for the ITS standards from ETSI. They are summarized in the following.

For CAM Release 2 standard TS 103 900:

- The CAM should include the data field MapPosition to address the intersection-cases described before, see clause 4.4.8. Alternatively, the data field GeneralizedLanePosition could be used instead.
- Allow a list of (at least 2) LanePositions, for those case where the identification of one lane is not possible, see clause 5.
- If the LanePosition is not accurate or helpful, alternatively the distances of the object to the left and right carriageway-border could be helpful and thus added to the CAM. This white paper did not investigate if such values can be measured by vehicles or roadside units. If such values can be provided, ETSI should discuss to include such elements.
- If of any value, the CAM should provide information about the method that was used to create the lane information (see clause 4.3.3).

For DENM Release 2 standard TS 103 831

- The points for the CAM are also applicable for the DENM and the DENM standard should be change accordingly.

For Collective Perception TS 103 324

- While the data field PerceivedObject already contains the data field MapPosition, the 'simple' LanePosition is not part of a PerceivedObject. Lane information of perceived objects could be helpful for the receiver and the TS 103 324 should support this. Either the data element LanePosition should be added or the more general data field GeneralizedLanePosition should replace the existing MapPosition. In any case, the PerceivedObject is already defined in the CDD ([RD-2]) and the corresponding change has to be done in the CDD.

For CDD Release 2 standard TS 102 894-2

- The description of the data element LanePosition should be updated to address the cases of:
  - Wrong way driving (like ghost drivers or overtaking on rural roads).
  - Odd number of lanes on a carriageway for bidirectional traffic.

  Reasons and proposals for both items are given in clause 6.1. An update or clarification in the CDD would directly transfer this change to users of the data element like CAM or DENM.

7 Appendix A – Related documents and references

[RD-1]	**C2C-CC Collaboration Area; WorkingGroup F0028, https://collab.car-2-car.org/index.php/f/69594**
[RD-2]	Intelligent Transport Systems (ITS); Users and applications requirements; Part 2: Applications and facilities layer common data dictionary (ETSI TS 102 894-2 V2.1.1);
[RD-3]	Glossary - CAR 2 CAR Communication Consortium, https://www.car-2-car.org/fileadmin/documents/Basic_System_Profile/Release_1.6.2/C2CCC_TR_2053_Glossary.pdf
[RD-4]	Glossary of road transport terms, https://en.wikipedia.org/wiki/Glossary_of_road_transport_terms, accessed 10.01.2022
[RD-5]	Road, https://en.wikipedia.org/wiki/Road, accessed 10.01.2022
[RD-6]	CONVENTION ON ROAD TRAFFIC - DONE AT VIENNA ON 8 NOVEMBER 1968, https://unece.org/DAM/trans/conventn/Conv_road_traffic_EN.pdf, accessed 24.02.2022
[RD-7]	Straßengesetz, https://dejure.org/gesetze/StrG/2.html, accessed 10.01.2022
[RD-8]	Bundesfernstraßengesetz, https://www.gesetze-im-internet.de/fstrg/BJNR009030953.html, accessed 10.01.2022
[RD-9]	ISO 17572-1:2015 Intelligent transport systems (ITS) — Location referencing for geographic databases — Part 1: General requirements and conceptual model https://www.iso.org/standard/63400.html
[RD-10]	ISO/TS 14812:2022 Intelligent transport systems — Vocabulary https://www.iso.org/standard/79779.html or https://github.com/ISO-TC204/iso14812
[RD-11]	ETSI TErms and Definitions Database Interactive (TEDDI) https://webapp.etsi.org/Teddi/, accessed 24.02.2022
[RD-12]	OpenStreetMap – Wiki: Key:lanes, https://wiki.openstreetmap.org/wiki/Key:lanes, accessed 11.04.2022
[RD-13]	Work Item Description - Road Configuration information for inclusion in DENMs, https://collab.car-2-car.org/index.php/f/76305
[RD-14]	ADASIS Organization Website; https://adasis.org/, accessed 01.09.2022
[RD-15]	ADASIS AISBL; ADASIS v3 Reference; Specification v3.1.0; October 01 2018; Can be requested via the ADASIS website [RD-14]
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