Technical Report on CPM Object Quality

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 works in close cooperation with the European and international standardisation organisations such as ETSI and CEN.

Disclaimer

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1 Introduction

1.1 Abstract

This document is the work result of an investigation study on object quality representation in CPM conducted in 2019/2020.

It shall serve as a basis for contributing to ETSI standardization of the CPM and also for further profiling in C2C-CC in the future.

1.2 Survey of document

This document consists of four main parts.

At first, the results from the literature review are provided. The following two chapters provide information on the work results for the representation of object accuracy and object confidence respectively. The last chapter lists a number of issues identified which could be relevant for later profiling of the CPM.

Every one of those chapters provides insights on the considerations and the work which has been done before providing a concrete proposal for changes in the ETSI TS 103 324 and the CPM ASN.1 definition.

1.3 Note about changes to ASN.1 files

Please note that this document proposes changes to the ASN.1 files of the CP Message. The proposed changes use the following commit of the ETSI CPM Repository as baseline: https://forge.etsi.org/rep/ITS/asn1/cpm_ts103324/commit/442bb2aef72b11759a51fe33eeb3104fb466ed62

The changes to the ASN.1 files will be provided as merge-requests to the ETSI working group. Changes to these files are documented below using “diff”-notation with “-“ indicating removed lines and “+” indicating added lines.

2 Literature review

2.1 General literature overview

As the initial question for the study allowed for a wide range of possible solutions, one of the first steps in the study was the analysis of current state of the art for object quality representation and the research for suitable concepts to consider for CPM. The findings of this research are presented in this chapter.

One of the first results from this literature review were the definitions of terms, which are described in detail in chapter 2.2.The second part of the research was the analysis of existing metrics on information and object quality. The basic findings of this research are presented in a separate, C2C-CC internal document [RD-1].

All considered literature relevant for this document is listed in chapter 6.2.

2.2 Definition of terms

In the context of data quality many different concepts and terms are used. Sometimes different terms are used to describe the same concepts, sometimes different people use the same term for different concepts.

Therefore it is crucial to build a common understanding of the concepts and terms to consider. This chapter provides all relevant terms for object quality in the context of CPM. For object quality two main concepts are considered relevant – the accuracy and the data quality. As measures for both of these concepts are rather different, they are considered individually.

The first clause in this section provides definitions of terms relevant for accuracy, the second clause contains the terms relevant for data quality.

2.2.1 Accuracy

A variety of different terms exists in the area of accuracy. The main sources for clear and unambiguous definitions for the document at hand are the ISO standard on definition of terms for accuracy [AD-1] and the ISO standard on definition of terms for statistics, [AD-3].

Table 3: Definition of terms related to accuracy

Term	Definition	Source
Accuracy	„Closeness of agreement between a test result and the accepted reference value“ Note: This „involves a combination of random components and a bias component“	[AD-1], cl 3.6
Bias	“The difference between the expectation of the test results and an accepted reference value” Note: This is the total systematic error	[AD-1], cl. 3.8
Confidence level	“Reflects the proportion of cases that the confidence interval would contain the true parameter value in a long series of repeated samples”	[AD-3], cl. 1.28
Confidence region	A multidimensional generalization of a confidence interval [1] (conf. interval: ISO 3534-1:2009, cl. 1.28),	[AD-5], [AD-3], cl. 1.28 (confidence interval)
Covariance	Expectation of the product of the deviation of two random variables from their mean	[AD-6]

	(Variance: covariance of a variable with itself)	
Covariance matrix	Matrix providing the covariance between each pair of elements on a given random vector	
Precision	"The closeness of agreement between independent test results obtained under stipulated conditions"; Note: It depends only on the distribution of random errors and doesn't relate to the true error	[AD-1], cl 3.12
Trueness	"Closeness of agreement between the average value obtained from a large series of test results and an accepted reference value"	[AD-1], cl. 3.7

The terms accuracy, precision and trueness are often treated as synonyms, which – according to the above definitions – is not fully correct. They are closely related, though. Figure 1 shows the meaning of these three terms.

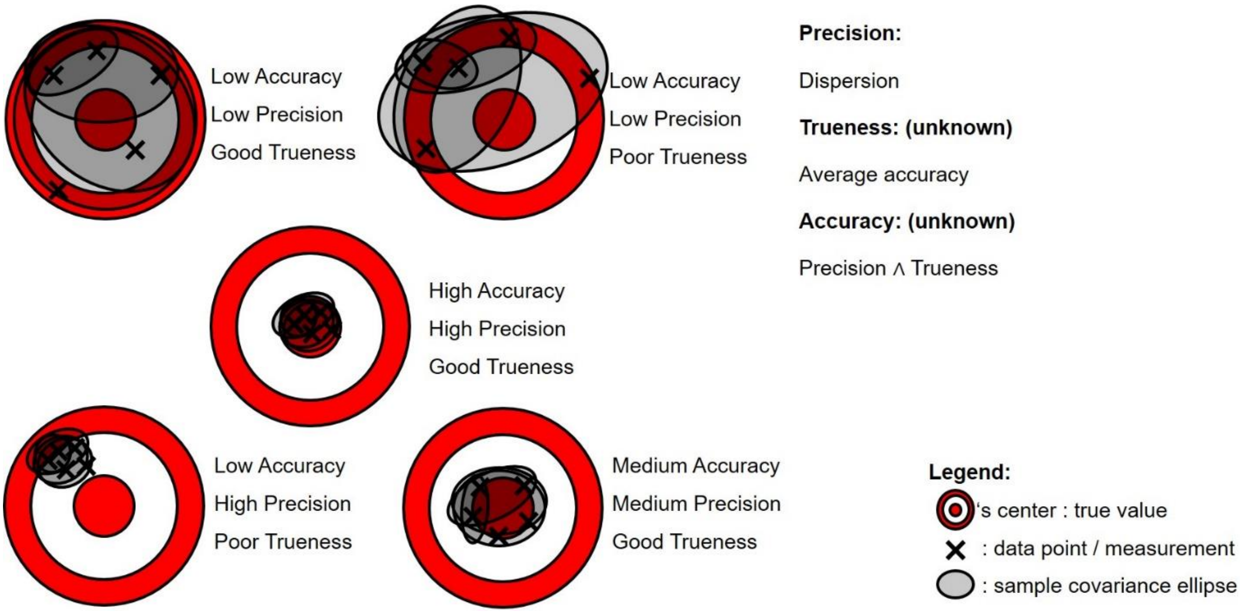


Figure 1: Relation of precision, trueness and accuracy

Finally, the following table allows for a better understanding of the relation between terms denoting general accuracy concepts and terms describing certain accuracy measurements. In summary, accuracy is the overarching concept which consists of both precision and trueness. Precision can be measured through covariance, whereas trueness is measured through the bias. As a result, the measurement for accuracy is the confidence.

This understanding is also in line with section "6.3.1 General requirements related to confidence" of ETSI EN 302 890-2 V2.1.1 (2020-10) [AD-7].

Table 4: Relation of accuracy concepts and measurements

Term	Measure	Term	Measure
Accuracy Precision ∧ Trueness	**Confidence region,** represented by covariance matrix and bias (2D-representation: confidence ellipse) **Confidence (level)**	**Precision** Dispersion	**Covariance** (-matrix [multi-dim])
		Trueness Accuracy of the average	**Bias** Total systematic error

2.2.2 Data quality

The term “data quality” is rather wide and abstract, therefore it is very important to have a clear view on the different terms associated with this concept. The main source for definition of terms is the ISO standard on data quality models for software engineering, [AD-2].

Term	Definition	Source
Completeness	“The degree to which subject data has values or all expected attributes and related entity instances.”	[AD-2], cl. 4.12
Consistency	“The degree to which data has attributes that are free from contradiction and are coherent with other data.”	[AD-2], cl. 5.3.1.3
Credibility	“The degree to which data has attributes that are regarded as true and believable by users.”	[AD-2], cl. 5.3.1.4
Currentness	“The degree to which data has attributes that are of the right age.”	[AD-2], cl. 5.3.1.5
Object confidence	Quantification of the confidence that a detected object actually exists in reality.	C2C-CC
Integrity	“Property of safeguarding the accuracy and completeness of assets.”	[AD-2], cl. 4.12
Plausibility (in context of CPM)	A result of the information’s inherent consistency and the evaluation of information with respect to the ITS station‘s own context	C2C-CC, F0014

2.3 Contribution to ETSI TS 103 324

The C2C-CC proposes an extension of clause 3.1 of ETSI TS 103 324 by the following terms and definitions:

Accuracy: Closeness of agreement between a test result and the accepted reference value“; NOTE: This „involves a combination of random components and a bias component

NOTE: The definition is compliant to ISO 5725-1:1997 *[i.x]*

Currentness: The degree to which data has attributes that are of the right age.

NOTE: The definition is compliant to ISO 25012:2008 *[i.y]*

Object confidence: Quantification of the confidence that a detected object actually exists, i.e., has been detected previously and has continuously been detected by a sensor.

Precision: The closeness of agreement between independent test results obtained under stipulated conditions

NOTE 1: Precision depends only on the distribution of random errors, it doesn't relate to the true error.

NOTE 2: The definition is compliant to ISO 5725-1:1997 *[i.x]*

Trueness: Closeness of agreement between the average value obtained from a large series of test results and an accepted reference value.

NOTE: The definition is compliant to ISO 5725-1:1997 *[i.x]*

Furthermore, the C2C-CC proposes an extension of the informative references in ETSI TS 103 324 by the following:

[i.x]	DIN/ISO 5725-1:1997: „Accuracy (trueness and precision of measurement methods and results – Part 1: General principles and definitions) “
[i.y]	ISO/IEC 25012:2008: "Software engineering – Software product Quality Requirements and Evaluation (SQuaRE) – Data quality model"
[i.z]	ISO 3534-1:2006: "Statistics – Vocabulary and symbols – Part 1: General statistical terms and terms used in probability"

3 Representation of object accuracy

One of the key research questions for the investigation study focused on how the accuracy of the kinematic state of an object shall be best represented in CPM.

This chapter provides insights to this work and its results. At first, the initial considerations are presented, thereafter the simulation and evaluation methodology is described before finally showing the key findings and results. In the last section the resulting proposed changes to ETSI 103 324 are given.

3.1 Considerations

3.1.1 Relevant state space

To find a proper concept for accuracy in the context of CPM, an agreement on the considered state space for which to express accuracy is needed.

The minimum information required for an object in CPM is its location and speed relative to the disseminating ITS-station, thus the minimum state space is

$$x = \begin{pmatrix} d_x \\ d_y \\ v_x \\ v_y \end{pmatrix}.$$

Therefore, accuracy information shall be given at least for this minimum state space, with possible extensions for acceleration, angle etc.

3.1.2 Confidence region and covariance matrix

As defined in subsection 2.2.1, accuracy incorporates both trueness and precision and is measured through a confidence region. A proper, efficient and loss-free representation of this confidence region is the main concern of this part of the investigation study.

The confidence region's appearance differs depending on the dimension of the considered state space. In one dimension, the confidence region is an interval, in two dimensions it is an ellipse and in three dimensions it is an ellipsoid. For higher dimensions, there is no human-perceivable representation available anymore.

All ellipsoids in an n-dimensional state space ($n \geq 1$) can be completely described through the orientation and lengths of their main axes (where the number of main axes equals the dimension number).

For a set of randomly distributed measurement samples (or sensor detections in the case of CPM) the covariance matrix is another way of representing the precision of the sample set. It contains the covariance for any two components of the state space.

The covariance matrix describes the accuracy of the current measurement. In other words, the covariance matrix details the shape of the ellipsoid, whereas the location / centre of the ellipsoid is described by the underlying mean of the distribution. The ellipsoid's main axes correspond to the normalized eigenvectors of the covariance matrix, the lengths of the axes are given by the corresponding eigenvalues.

3.1.3 Concepts for reduced covariance representation in CPM

The most complete representation of the covariance is to use the complete covariance matrix. As the covariance matrix is symmetric, only the lower triangular matrix is required.

$$C = \begin{pmatrix} cov(d_x, d_x) & & & \\ cov(d_x, d_y) & cov(d_y, d_y) & & \\ cov(d_x, v_x) & cov(d_y, v_x) & cov(v_x, v_x) & \\ cov(d_x, v_y) & cov(d_y, v_y) & cov(v_x, v_y) & cov(v_y, v_y) \end{pmatrix}$$

For the minimal state space as shown above, this results in ten required values. With every extension of the state space, this amount is growing drastically (e.g. extension for acceleration in two dimensions already requires 21 values).

Therefore four more concepts for reduced covariance representation were considered in the investigation study:

Block covariance:

Consideration of only the individual 2x2 covariance matrices for position and speed (and other parameters) are considered:

$$C_{block} = \begin{pmatrix} cov(d_x, d_x) & & 0 & 0 \\ cov(d_x, d_y) & cov(d_y, d_y) & 0 & 0 \\ 0 & 0 & cov(v_x, v_x) & \\ 0 & 0 & cov(v_x, v_y) & cov(v_y, v_y) \end{pmatrix}$$

Variance:

Consideration of only the variances (main diagonal of the covariance matrix). This is also what is currently expressed in the position and speed confidences for the objects in the CPM (there, standard deviation is used, which is the square-root of the variance).

$$C_{var} = \begin{pmatrix} cov(d_x, d_x) & 0 & 0 & 0 \\ 0 & cov(d_y, d_y) & 0 & 0 \\ 0 & 0 & cov(v_x, v_x) & 0 \\ 0 & 0 & 0 & cov(v_y, v_y) \end{pmatrix}$$

LDL decomposition:

This concept doesn't consist in the reduction of matrix elements required but in date reduction through smaller value ranges required for the representation. In this concept, the sender performs an L-D-L decomposition and transmits only the lower triangular matrix L and the diagonal matrix D with lower precision than the original covariance matrix. The receiver then can reinstate the full covariance matrix with little loss of information.

$$L = \begin{pmatrix} 1 & 0 & 0 & 0 \\ a & 1 & 0 & 0 \\ b & c & 1 & 0 \\ d & e & f & 1 \end{pmatrix}, D = \begin{pmatrix} h & 0 & 0 & 0 \\ 0 & i & 0 & 0 \\ 0 & 0 & k & 0 \\ 0 & 0 & 0 & l \end{pmatrix}$$

Standard deviations and correlation:

With this concept data reduction is also intended to be achieved through smaller value ranges required. Standard deviations are already part of the current CPM data structure (expressed as confidence for each value). In combination with the correlation, the receiver can reinstate the covariance.

$corr(a, b) = \frac{1}{\sigma_A \sigma_B} cov(A, B)$; where σ_A denotes the standard deviation of A.

$$Corr = \begin{pmatrix} 1 & & & \\ corr(d_x, d_y) & 1 & & \\ corr(d_x, v_x) & corr(d_y, v_x) & 1 & \\ corr(d_x, v_y) & corr(d_y, v_y) & corr(v_x, v_y) & 1 \end{pmatrix}$$

3.1.4 Explanation for the basic implications

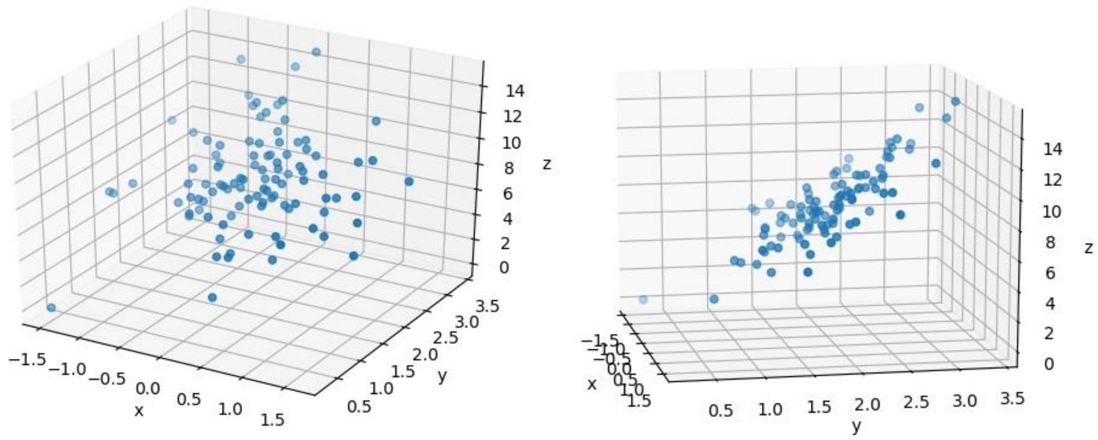
The reduced representations above are rather abstract. One can imagine that there is a loss of information for every reduction made but the implications of that loss are not clear.

The basic principles can be understood when looking into a simple, 3D example.

This example takes 100 normally distributed samples as follows:

- x_i is distributed with $\mathcal{N}(0.0, 0.6, 100)$, for $i \in [1,100]$
- y_i is distributed with $\mathcal{N}(2.0, 0.5, 100)$, for $i \in [1,100]$
- z_i is distributed with $\mathcal{N}(4 * \mathrm{y_i}, 0.7, 100)$, for $i \in [1,100]$

This results in the following sample set where the z component as quite some correlation with the y component:



The full covariance information and an additional scaling to fit 95% of all samples (through the Chi-squared function) results in an ellipsoid nicely fitting the sample set:

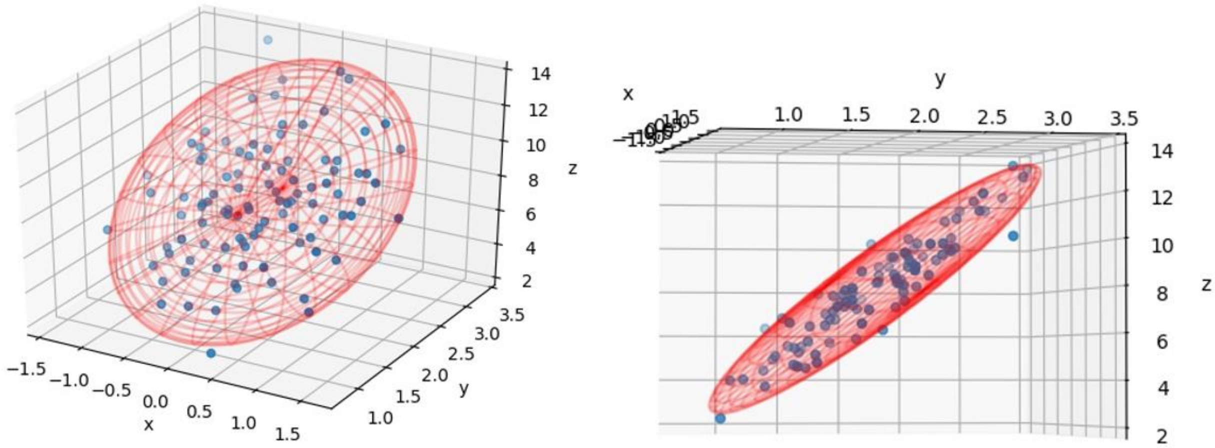


Figure 2: Covariance ellipsoid, scaled to 95%

If now only the variances are used to create the ellipsoid, the resulting ellipsoid still fits 95% of the samples but since the information about the relation between the components is missing, the ellipsoid is a ball of much higher volume than the original covariance ellipsoid:

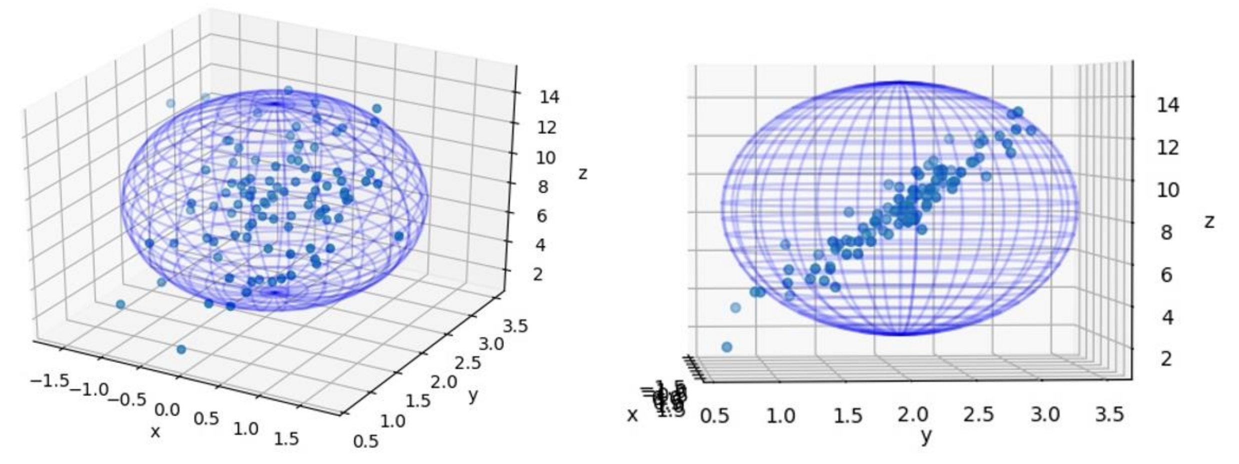


Figure 3: Variance ellipsoid, scaled to 95%

The above mentioned concept of using block covariance can be represented in this simplified example by using the block-covariance for the two components and only variance for the third component. Of course the effects on the ellipsoid differ depending on the relation between the components. Since only the z-component has a correlation to the y-component, omitting the information of this correlation results in an ellipsoid similar to the variance ellipsoid. On the other hand, the omission of the covariance between x and y results in an ellipsoid similar to the full covariance ellipsoid (almost no information is lost).

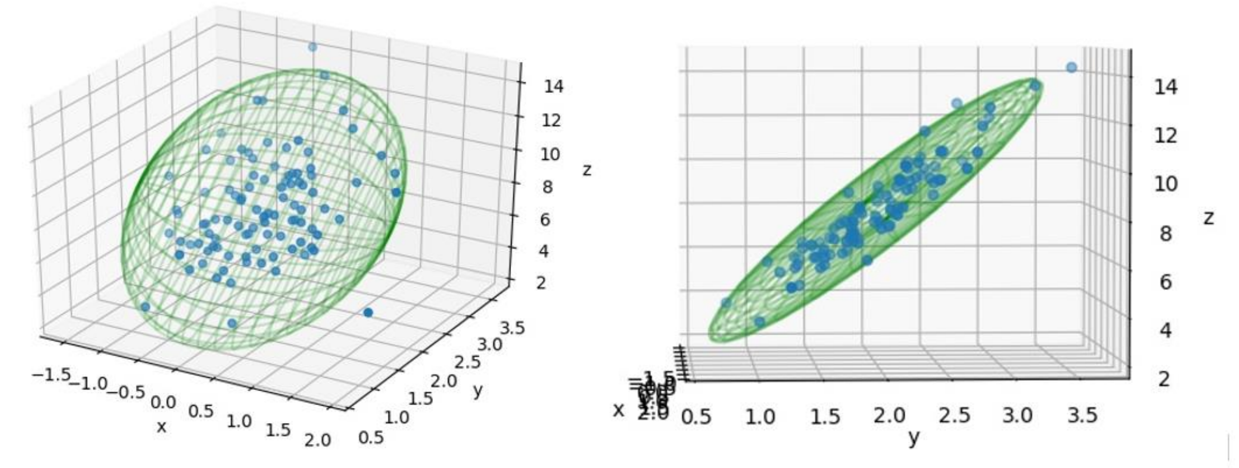


Figure 4: y-z block covariance, x variance separate

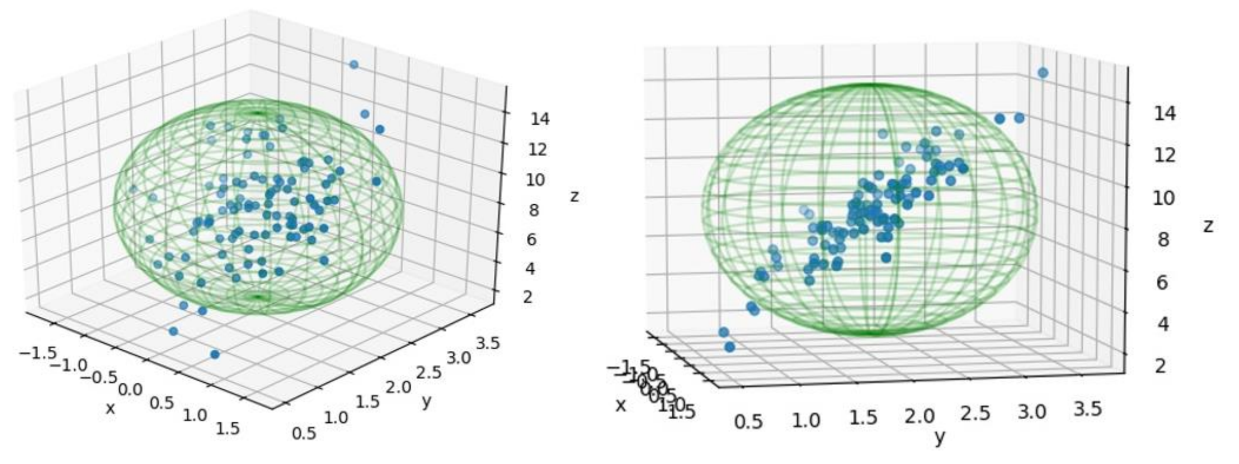


Figure 5: x-y block covariance, z variance separate

3.2 Methodology

The implications of the different options for accuracy representation in CPM were analysed through a simulation. This section describes the simulation setup and the employed key performance indicators (KPIs).

The general setup of the simulation consisted of two parts which are shown in Figure 6. IAV's own tool SceneSuite was used to create the scenarios, model corresponding sensor setups and provide the corresponding movement and sensor data to the evaluation tool implemented in Python. In this python tool a basic Kalman filter, the CPM accuracy information options and a corresponding evaluation was implemented.

The following sections provide some more details for the SceneSuite and Python setup respectively.

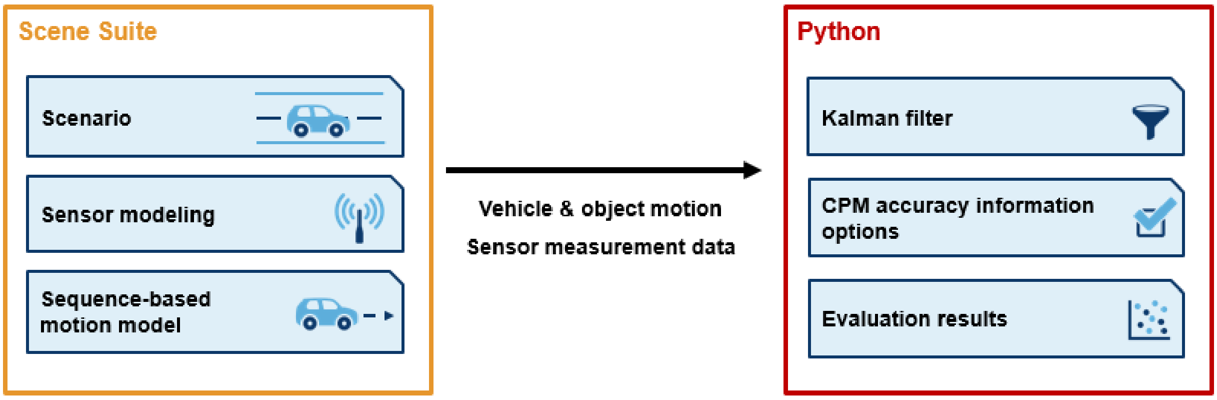


Figure 6: Simulation Setup

3.2.1 Scene Suite

The SceneSuite is a 2D simulation tool owned by IAV GmbH used for scene based function development. Its basic functionality provides the options to create driving scenarios with several vehicles and objects and at detailed, probabilistic sensor modelling for object detection.

For this simulation study two basic scenarios where created. Both consist of a straight road for a topology, one ego vehicle and a second vehicle serving as object to be detected by the ego. Figure 7 shows this general setup. The ego vehicle driving in the back is equipped with two sensors, one radar and one lidar. The smaller blue cone represents the field of view (FOV) of the radar, the bigger red cone represents the FOV of the lidar.

The difference between the two scenarios shows in the movement of the second vehicle. In the first scenario, the second vehicle accelerates and decelerates in longitudinal direction to the ego vehicle. Thus entering and leaving the sensors' FOVs longitudinally. In the second scenario, the longitudinal velocity of the second vehicle doesn't change but it moves in a sine-curve, thus entering and leaving the sensor's FOVs laterally.

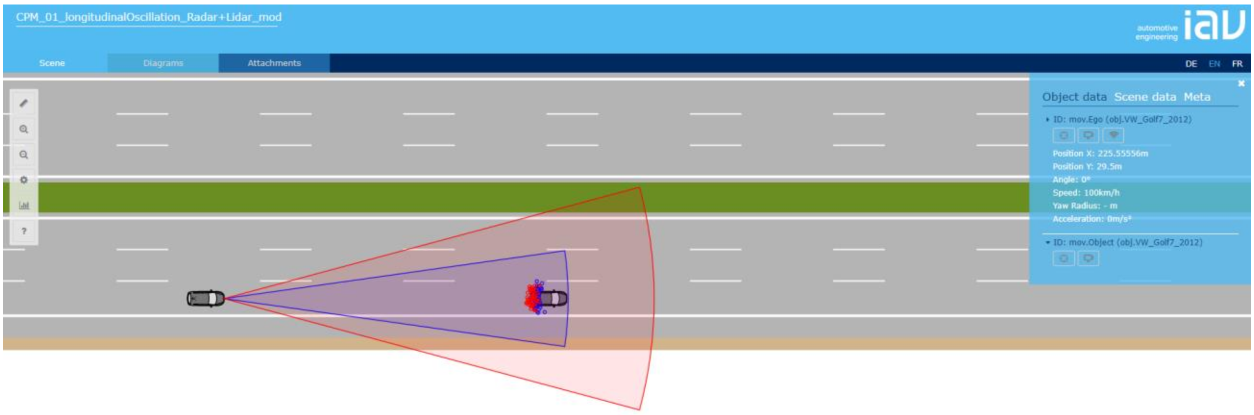


Figure 7: SceneSuite scenario

As explained earlier, sensors in scene suite are simulated with a probabilistic model. For the sake of this simulation a set of variations has been conducted, with 50 simulation runs per variation.

The table below shows the variations used,

Parameter	Default value	Variations
Sensor range (radar, lidar)	(40, 50) m	{(40, 50), (50, 40)} m
Left / right angle of FOV (radar, lidar)	(8, 15) °	{(8, 15), (15, 8)} °

Accuracy	**Radar:**
	Pos: $\mu_x = 0.617$, $\sigma_x = 0.171$, $\mu_y = -0.031$, $\sigma_y = 0.637$ (in m)
	Velo: $\mu_x = 0.045$, $\sigma_x = 0.44$, $\mu_y = 0.062$, $\sigma_y = 1.93$ (in m/s)
	Accel: $\mu_x = 0$, $\sigma_x = 0.5$, $\mu_y = 0$, $\sigma_y = 0.5$ (in m/s²)
	Lidar:
	Pos: $\mu_r = 0$ m, $\sigma_r = 0.3$ m, $\mu_\varphi = 0°$, $\sigma_\varphi = 1°$
	(old values: $\sigma_r = 0.033$ m, $\sigma_\varphi = 0.000264°$)
		{
		Default,
		radar degradation by factor 2,
		lidar degradation by factor 2
		}

Latency (same values for radar and lidar)	Not active (0.0 s)	{ 0.0, 0.1, 0.2} s

The simulation provides a logfile with all relevant simulation data which later can be read in the Python tool. The log file provides the following data:

- Time vector
- The following information is available for every time step:
  - Movement data of ego vehicle and object:
    - Absolute position in m (x & y)
    - Absolute speed in m/s (x & y)
    - Absolute acceleration in m/s² (x & y)
  - Measurement data of object of each sensor:
    - Relative & absolute position in m (x & y)
    - Relative & absolute speed in m/s (x & y)

- Relative & absolute acceleration in m/s² (x & y)Sensor configuration

3.2.2 Python

All further data processing (such as Kalman filtering and computation of the different accuracy options) where implemented separately in Python, as well as the evaluation of the results. Figure 8 shows the general structure implemented.

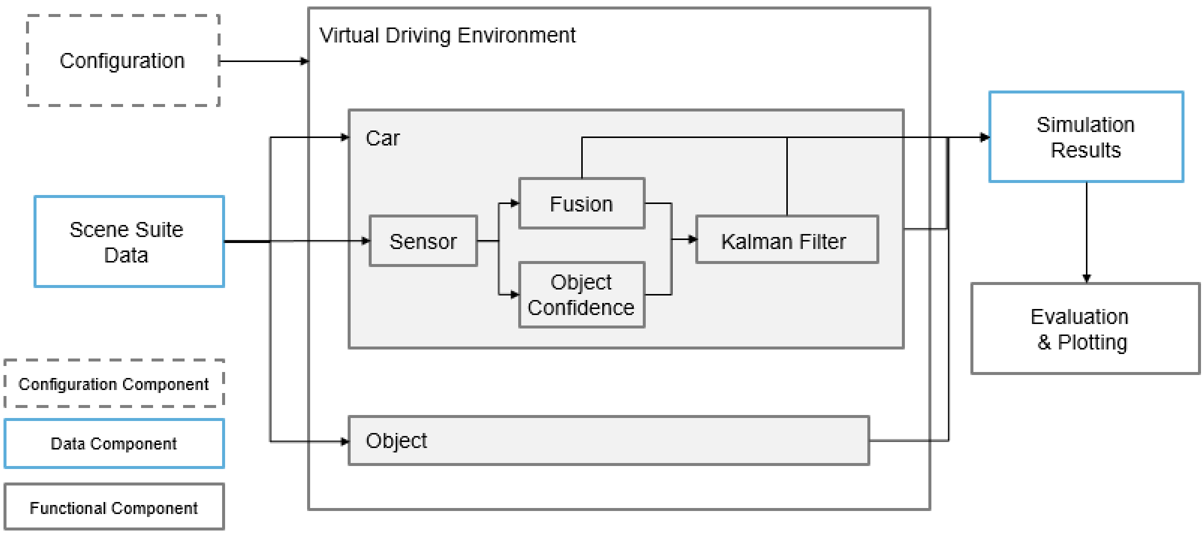


Figure 8: Python structure

In the simulation study the Kalman filter has a key role. One of the "side-results" of a Kalman filter is a covariance matrix. This covariance matrix is used as the core of accuracy information provided. All accuracy options explained in section 3.1.3 are computed from this covariance matrix resulting from the Kalman process.

The basic Kalman filter used in this simulation study was implemented and configured as follows:

Symbols:

- x: state vector [x, y, x', y', x'', y'']
- P: covariance matrix
- F: dynamic function
- m: motion noise
- Q: covariance of motion noise
- K: Kalman gain
- H: measurement matrix
- R: covariance of measurement noise
- z: measurement [x, y, x', y']
- I: identity matrix
- φ: relative angle between ego and object
- σ: deviation for the respective component (as configured for the simulated sensors)

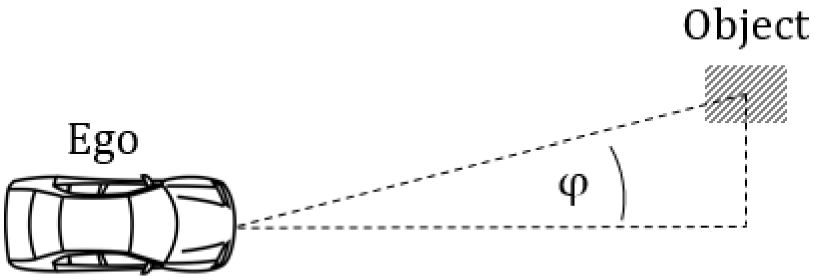
Initialization:

- x = [None, None, …, None]T and initialization with first measurement values
- P_0 = I
- F according to motion model
- m = [0, 0, …, 0]T
- Q = I * 0.001
- H is 4x6 matrix with ones on diagonal, rest zeros
- R = diag([σ_{x1}^2, σ_{x2}^2, σ_{y1}^2, σ_{y2}^2]) for φ = 0

Process:

The R matrix is updated in each step by rotation according to the current relative position of the object: $R(\varphi) = M_{rot}(\varphi) * R * M_{rot}(\varphi)^T$

$$\text{with } M_{rot} = \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 & 0 \\ \sin\varphi & \cos\varphi & 0 & 0 \\ 0 & 0 & \cos\varphi & -\sin\varphi \\ 0 & 0 & \sin\varphi & \cos\varphi \end{bmatrix}$$



- Predict step
  - Predict state: x = Fx + m
  - Predict covariance matrix: P = FPFT + Q
- Update step
  - Compute Kalman gain: $K = PHT (HPHT + R)^{-1}$
  - Update state estimate: x = x + K (z - Hx)
- Update covariance matrix: P = (I – KH) P

3.2.3 Key performance indicators

Before the actual simulation evaluation it is important to identify relevant key performance indicators (KPIs).

Covariance matrices can be “translated” to a covariance ellipsoid (or ellipse for two dimensions). The full covariance matrix provides the “true” covariance ellipsoid. The other options considered basically consist of a reduction of the full covariance matrix, thus also leading to different ellipsoids.

Ideally, the results from the Kalman filter are very close to the true state of the object, the ellipsoid is very small but still large enough to contain the true state of the object. From this considerations, three KPIs where identified for later evaluation:

- Volume of the ellipsoid scaled to 95% (in case of the simulation study: 4D)
- 95% percentile of the additional scaling factor (factor the ellipsoid needs to be scaled with to make it contain the true state of the object)
- Matrix similarity.

Where the first two indicators directly result from the previous consideration (the smaller the volume and the smaller the additional factor needed, the better), the third requires additional explanation.

The first two indicators are of a “geometrical” nature, allowing to compare the covariance ellipses. They don’t provide a direct comparison of the covariance matrices. Receiving vehicles may however want to employ processes which would benefit from the covariance information provided in CPM being mathematically as close as possible to the original covariance matrix. Therefore, the following metric was used for matrix comparison: $d(A,B) = \sqrt{\sum_{i=1}^{n} ln^2 \lambda_i(A,B)}$ with the eigenvalues $\lambda_i(A,B)$ from $|\lambda A - B| = 0$

It provides a “distance” for two symmetrical, positive definite matrices A and B (covariance matrices always fulfill these conditions). The metric was introduced by Wolfgang Förstner in 1999, [AD-4].

3.3 Findings & Resulting concept

3.3.1 Simulation results and KPIs

As explained earlier, several simulation runs with different simulation variations and configurations have been conducted. However, all these different settings didn't lead to significant differences in the KPIs.

Therefore, in the following only exemplary plots for the second scenario (lateral movement of the "object" vehicle) in two variations are shown. In the figures, the left plot corresponds to the default setting in the simulation, the right plot shows the results for when degrading the accuracy of the lidar by factor 2.

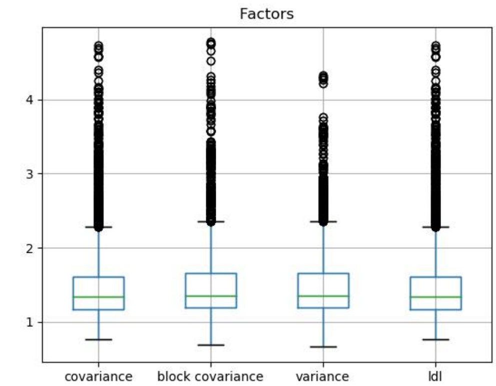


Figure 9: Scaling factors, 2nd scenario, default settings

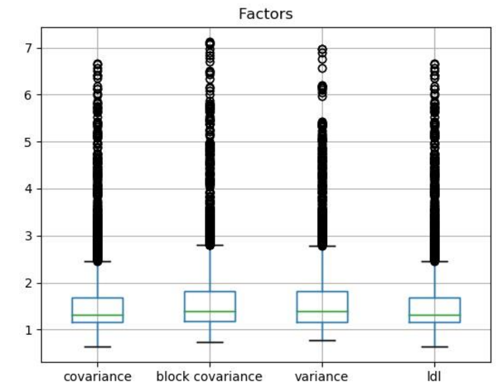


Figure 10: Scaling factors, 2nd scenario, lidar degradation

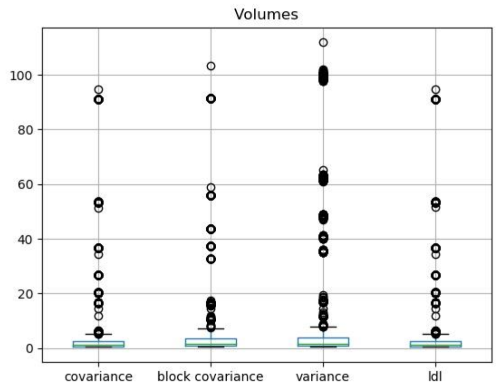


Figure 11: Volumes, 2nd scenario, default settings

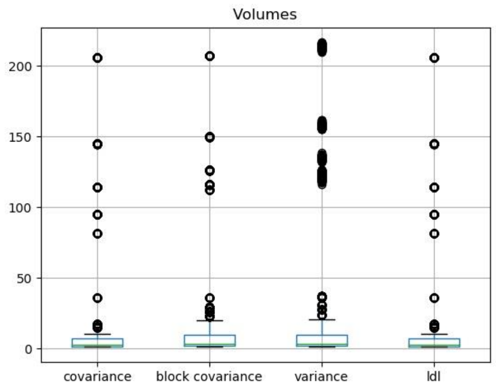


Figure 12: Volumes, 2nd scenario, lidar degradation

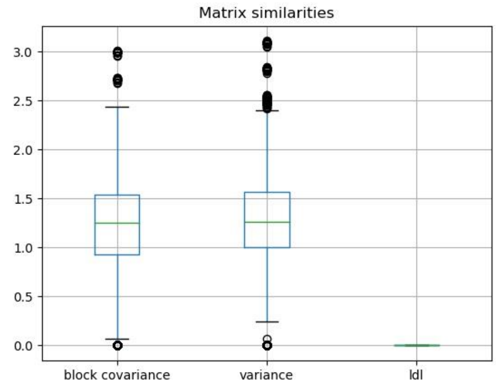


Figure 13: Matrix similarities, 2nd scenario, default settings

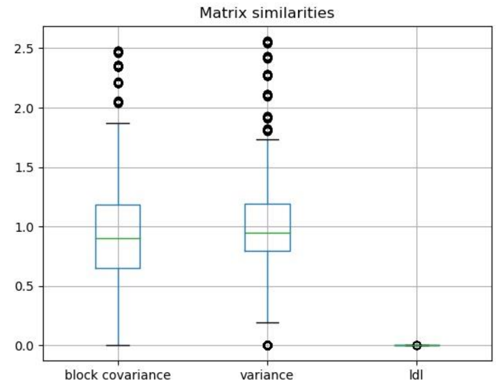


Figure 14: Matrix similarities, 2nd scenario, lidar degradation

These evaluation plots show that the different scenario variations in the simulation do not result in noticeable differences in the KPIs. Moreover, the different accuracy representation options also do not differ significantly with regards to the chosen KPIs. Only the matrix similarity metric shows that the LDL decomposition is closer to the original full covariance matrix by several factors compared to the block covariance matrix and the variance.

As the simulation represents a simplified analysis environment, the corresponding reduction in complexity results in very similar results for the different KPIs.

This consideration leads to the decision to only further evaluate the full covariance and the LDL decomposition instead of taking the risk that actual qualitative losses occur in real world applications when only using block covariance or variance.

In addition to the analysis of the KPIs also the resulting data size for the different options was considered.

Table 5: Assessment of rough data sizes in CPM for the different accuracy options

Option	**Value range in ASN.1**	**Data size per object** (assuming the minimum 4D state space)
Full covariance	±16 383 (15 bit)	10* 15 bit = 150 bit
LDL decomposition	0..16383 (14 bit) - diagonal entries ± 255 (9 bit) - lower triangular entries	4 * 14 bit + 6 * 9 bit = 110 bit

As was to be expected, the LDL decomposition requires less data and would be preferable from this perspective.

But the LDL has the downside that the contained values are not as easy to interpret as e.g. covariance values. Engineers wanting to analyse and debug applications wouldn’t be able to identify whether or not there is a problem in the accuracy values on one glance. Therefore a new option was considered – using correlation instead of covariance.

A representation of accuracy through standard deviation and correlation can be interpreted on a high level on first glance by engineers since there is a direct relation to the concerned state space entries. Additionally, this representation requires similar data sizes as the LDL decomposition. Therefore, this representation of accuracy combines the best qualities of full covariance and LDL decomposition.

Using standard deviation and correlation shall be proposed to ETSI for accuracy representation in CPM (indication of correlation options being optional).

3.3.2 Considerations for Cartesian coordinate systems

Throughout the analysis, a brief consideration of alternative coordinate systems other than a Cartesian reference system has been performed. One promising candidate is the utilization of a polar coordinate system, as measurement inaccuracy for many on-board or stationary sensors are initially provided in polar coordinates due to their measurement principle. Within a polar reference frame, the mean of a distribution would be presented by a pair of distance and angular component (r, ϕ). The corresponding covariance matrix would then also be represented in a polar coordinate system, which would greatly simplify and reduce the number of elements to be transmitted. Covariance values in a Cartesian reference frame would simply be represented by a diagonal matrix in a polar reference frame, as illustrated by the following example:

- Representation of a covariance matrix in polar coordinates for a measurement with an angle accuracy of 1° and a distance accuracy of 40 cm would be represented as

$$cov_{pol} = \begin{bmatrix} 1600 & 0 \\ 0 & 1 \end{bmatrix}$$

- For an object detected at an exemplary distance of 2300 m at an angle of e.g. 45°, this would be translated to a corresponding covariance matrix in a Cartesian coordinate system as

$$cov_{cart} = \begin{bmatrix} 1606 & -6 \\ -6 & 1606 \end{bmatrix}$$

However, while reducing the elements to be transmitted, this principle can only be applied for a single sensor system. As soon as multiple sensors are mounted to the detecting station, or the sensor's reference frame does not coincide with the CPM's reference frame, relative rotational components result in non-diagonal covariance elements upon data fusion.

Additionally, the required data range for each component to be transmitted is similar to the range required in a Cartesian reference frame, therefore not providing any additional benefit for the resulting message size.

3.4 Contribution to ETSI TS 103 324

The C2C-CC proposes an extension of clause 7.6. of ETSI TS 103 324 as follows:

7.6 Perceived Object Container

One key goal of the CPM is to share information about perceived objects. For that purpose, the kinematic attitude state along with additional information on an object is provided through the Perceived Object Container.

7.6.1 The kinematic attitude state of an object

The full kinematic attitude state of an object shall be represented in an 18-dimensional kinematic state and attitude space.

The corresponding state vector shall be represented as

$$\text{state}_{\text{Obj}} = \left(d_x, d_y, d_z, v_x, v_y, v_z, a_x, a_y, a_z, \theta_{roll}, \theta_{pitch}, \theta_{yaw}, \omega_{roll}, \omega_{pitch}, \omega_{yaw}, \alpha_{roll}, \alpha_{pitch}, \alpha_{yaw}\right)^T$$

with d_i, v_i, a_i representing the distance, speed and acceleration and $\theta_i, \omega_i, \alpha_i$, correspondingly representing angle and angular speed and acceleration.

7.6.2 Concept of the Perceived Object Container

<Current content of clause 7.6>

7.6.3 Representation of accuracy

For every component provided in the kinematic state and attitude space of an object in the CPM, in accordance to Clause 7.6.1, the corresponding standard deviation of the Probability Density Function (PDF) shall be provided to a pre-defined confidence level (e.g., 95 %).

In addition, correlation information may be provided for each component. If correlation information is provided, the number of correlation entries shall correspond to the size of the kinematic state and attitude space, i.e. given a state space vector of length n, the corresponding correlation matrix has to be of size n x n. Correlation is represented in a vectorised form for each column of the corresponding lower-triangular positive semidefinite correlation matrix ordered in the same fashion as the provided kinematic attitude state components stated in Clause 7.6.1. The correlation is mathematically symmetric i.e., $corr(x,y) = corr(y,x)$ for any two given random variables. Therefore, every component of the kinematic attitude state shall only provide the correlation information with the remaining, subsequent components.

Additionally we propose to provide the following example in an annex:

See the following example for a better understanding: Supposed, a sender provides distance and speed in the x-y-plane as well as the yaw angle. The corresponding state vector is $(d_x, d_y, v_x, v_y, \theta_{yaw})^T$ with correlation matrix

$$Corr = \begin{bmatrix} 1 & corr_{\{d_x d_y\}} & corr_{\{d_x v_y\}} & corr_{\{d_x v_y\}} & corr_{\{d_x \theta_{yaw}\}} \\ corr_{\{d_x d_y\}} & 1 & corr_{\{d_y v_x\},} & corr_{\{d_y v_y\}} & corr_{\{d_y \theta_{yaw}\}} \\ corr_{\{d_x v_x\},} & corr_{\{d_y v_x\},} & 1 & corr_{\{v_x v_y\}} & corr_{\{v_x \theta_{yaw}\}} \\ corr_{\{d_x v_y\}} & corr_{\{d_y v_y\}} & corr_{\{v_x v_y\}} & 1 & corr_{\{v_y \theta_{yaw}\}} \\ corr_{\{d_x \theta_{yaw}\}} & corr_{\{d_y \theta_{yaw}\}} & corr_{\{v_x \theta_{yaw}\}} & corr_{\{v_y \theta_{yaw}\}} & 1 \end{bmatrix},$$

It follows that given our state vector of length 5, to represent the corresponding correlation information in the CPM for this object, 5-1 columns with 5-i correlation values per in the i[th] column are required.

In this example, the correlation matrix for the state vector shall be represented by

LowerTriangularPositiveSemidefiniteMatrix = [

$[corr_{\{d_x d_y\}}, corr_{\{d_x v_x\},} corr_{\{d_x v_y\}}, corr_{\{d_x \theta_{yaw}\}}]$,

$[corr_{\{d_y v_x\},} corr_{\{d_y v_y\}}, corr_{\{d_y \theta_{yaw}\}}]$,

$[corr_{\{v_x v_y\}}, corr_{\{v_x \theta_{yaw}\}}]$,

$[corr_{\{v_y \theta_{yaw}\}}]$

],

where every list of correlations corresponds to a data frame of type correlationColumn and every entry within a correlationColumn corresponds to a data element of type correlationRowValue.

From here, the receiver can compute the corresponding covariance matrix $\mathbf{C}$. Given the diagonal matrix $\mathbf{A} = \mathrm{diag}(\sigma_1, \ldots, \sigma_n)$ of standard deviations for the received kinematic state and attitude vector, and the correlation matrix $\mathbf{D} = \begin{pmatrix} 1 & \cdots & corr \\ \vdots & \ddots & \vdots \\ corr & \cdots & 1 \end{pmatrix}$, constructed from the received lower triangular matrix components, the covariance matrix can be computed as $\mathbf{C} = \mathbf{ADA}$.

We propose the following changes and additions to the ASN definition.

Changes in PerceivedObject.asn:

```
--- a/asn/PerceivedObject.asn
+++ b/asn/PerceivedObject.asn
@@ -8,9 +8,9 @@ BEGIN

 IMPORTS

-Acceleration, CartesianAngle, DynamicStatus, Identifier, MatchedPosition,
-NumberOfPerceivedObjects, ObjectAge, ObjectConfidence, ObjectClassDescription, ObjectDimension,
-ObjectDistance, ObjectRefPoint, SensorIdList, SpeedExtended, TimeOfMeasurement
+Acceleration, CartesianAngle, CartesianAngularAcceleration, CartesianAngularSpeed,
DynamicStatus, Identifier,
+LowerTriangularPositiveSemidefiniteMatrix, MatchedPosition, NumberOfPerceivedObjects,
ObjectAge, ObjectConfidence,
+ObjectClassDescription, ObjectDimension, ObjectDistance, ObjectRefPoint, SensorIdList,
SpeedExtended, TimeOfMeasurement
```

```
 FROM CPM-CommonDataTypes-Descriptions {itu-t (0) identified-organization (4) etsi (0) itsDomain
(5) wg1 (1) ts (103324) commonDataTypes (2) version1 (1)};

 /** @brief Perceived Object Container
@@ -45,91 +45,191 @@ PerceivedObject ::= SEQUENCE {
     measurement of the object.
     */
     timeOfMeasurement       TimeOfMeasurement,
-    /** @details objectConfidence
-    The confidence associated to the object.
-    */
-    objectConfidence        ObjectConfidence DEFAULT 0,
     /** @details xDistance
-    Absolute distance to detected object from the ITS-S's reference point in x-direction for
the
-    time of measurement. For a vehicle, the distance is reported in a body-fixed coordinate
system
+    Distance to detected object from the ITS-S's reference point in x-direction for the time
+    of measurement. For a vehicle, the distance is reported in a body-fixed coordinate system
     as provided by ISO 8855. For a RSU, the distance is reported in a coordinate system in which
     the y-axis corresponds to the North direction, the x-axis to the East direction, and the z-
     axis to the vertical direction.
     */
     xDistance               ObjectDistance,
     /** @details yDistance
-    Absolute distance to detected object from the ITS-S's reference point in y-direction for
the
-    time of measurement. For a vehicle, the distance is reported in a body-fixed coordinate
system
+    Distance to detected object from the ITS-S's reference point in y-direction for the time
+    of measurement. For a vehicle, the distance is reported in a body-fixed coordinate system
     as provided by ISO 8855. For a RSU, the distance is reported in a coordinate system in which
     the y-axis corresponds to the North direction, the x-axis to the East direction, and the z-
-    axis to the vertical direction.
+    axis to the vertical direction
     */
     yDistance               ObjectDistance,
     /** @details zDistance
-    Absolute distance to detected object from the ITS-S's reference point in z-direction for
the
-    time of measurement. For a vehicle, the distance is reported in a body-fixed coordinate
system
+    Distance to detected object from the ITS-S's reference point in z-direction for the time
+    of measurement. For a vehicle, the distance is reported in a body-fixed coordinate system
     as provided by ISO 8855. For a RSU, the distance is reported in a coordinate system in which
     the y-axis corresponds to the North direction, the x-axis to the East direction, and the z-
-    axis to the vertical direction.
+    axis to the vertical direction
     */
     zDistance               ObjectDistance OPTIONAL,
     /** @details xSpeed
-    Relative speed of the detected object from the ITS-S's reference point in x-direction for
the
-    time of measurement. For a vehicle, the speed is reported in a body-fixed coordinate system
-    as provided by ISO 8855. For a RSU, the speed is reported in a coordinate system in which
-    the y-axis corresponds to the North direction, the x-axis to the East direction, and the z-
-    axis to the vertical direction.
+    Speed of the detected object in the detecting ITS-S's reference system in x-direction for
the
+    time of measurement (i.e. speed of the object relative to the origin of the station's
reference
```

```
+    system). For a vehicle, the speed is reported in a body-fixed coordinate system as provided
by
+    ISO 8855 originating at the ITS-station's reference point. For a RSU, the speed is reported
in
+    a coordinate system in which the y-axis corresponds to the North direction, the x-axis to
the
+    East direction, and the z-axis to the vertical direction.
     */
     xSpeed                    SpeedExtended,
     /** @details ySpeed
-    Relative speed of the detected object from the ITS-S's reference point in y-direction for
the
-    time of measurement. For a vehicle, the speed is reported in a body-fixed coordinate system
-    as provided by ISO 8855. For a RSU, the speed is reported in a coordinate system in which
-    the y-axis corresponds to the North direction, the x-axis to the East direction, and the z-
-    axis to the vertical direction.
+    Speed of the detected object in the detecting ITS-S's reference system in y-direction for
the
+     time of measurement (i.e. speed of the object relative to the origin of the station's
reference
+    system). For a vehicle, the speed is reported in a body-fixed coordinate system as provided
by
+    ISO 8855 originating at the ITS-station's reference point. For a RSU, the speed is reported
in
+    a coordinate system in which the y-axis corresponds to the North direction, the x-axis to
the
+    East direction, and the z-axis to the vertical direction.
     */
     ySpeed                    SpeedExtended,
     /** @details zSpeed
-    Relative speed of the detected object from the ITS-S's reference point in z-direction for
the
-    time of measurement. For a vehicle, the speed is reported in a body-fixed coordinate system
-    as provided by ISO 8855. For a RSU, the speed is reported in a coordinate system in which
-    the y-axis corresponds to the North direction, the x-axis to the East direction, and the z-
-    axis to the vertical direction.
+    Speed of the detected object in the detecting ITS-S's reference system in z-direction for
the
+     time of measurement (i.e. speed of the object relative to the origin of the station's
reference
+    system). For a vehicle, the speed is reported in a body-fixed coordinate system as provided
by
+    ISO 8855 originating at the ITS-station's reference point. For a RSU, the speed is reported
in
+    a coordinate system in which the y-axis corresponds to the North direction, the x-axis to
the
+    East direction, and the z-axis to the vertical direction.
     */
     zSpeed                    SpeedExtended OPTIONAL,
     /** @details xAcceleration
-    Relative acceleration of the detected object from the ITS-S's reference point in x-direction
+    Acceleration of the detected object from the ITS-S's reference point in x-direction
     for the time of measurement. For a vehicle, the acceleration is reported in a body-fixed
-    coordinate system as provided by ISO 8855. For a RSU, the acceleration x-axis corresponds
to
-    the East direction.
+    coordinate system as provided by ISO 8855 originating at the ITS-station's reference point.
+    For a RSU, the acceleration is reported in a coordinate system in which the y-axis corresponds
+     to the North direction, the x-axis to the East direction, and the z-axis to the vertical
direction.
     */
     xAcceleration             Acceleration OPTIONAL,
```

```
     /** @details yAcceleration
-   Relative acceleration of the detected object from the ITS-S's reference point in y-direction
+    Acceleration of the detected object from the ITS-S's reference point in y-direction
     for the time of measurement. For a vehicle, the acceleration is reported in a body-fixed
-    coordinate system as provided by ISO 8855. For a RSU, the acceleration y-axis corresponds
to
-    the North Direction.
+   coordinate system as provided by ISO 8855 originating at the ITS-station’s reference point.
+   For a RSU, the acceleration is reported in a coordinate system in which the y-axis corresponds
+    to the North direction, the x-axis to the East direction, and the z-axis to the vertical
direction.
     */
     yAcceleration           Acceleration OPTIONAL,
     /** @details zAcceleration
-   Relative acceleration of the detected object from the ITS-S's reference point in z-direction
+    Acceleration of the detected object from the ITS-S's reference point in z-direction
     for the time of measurement. For a vehicle, the acceleration is reported in a body-fixed
-    coordinate system as provided by ISO 8855. For a RSU, the acceleration z-axis corresponds
to
-    the vertical direction.
+   coordinate system as provided by ISO 8855 originating at the ITS-station’s reference point.
+   For a RSU, the acceleration is reported in a coordinate system in which the y-axis corresponds
+    to the North direction, the x-axis to the East direction, and the z-axis to the vertical
direction.
     */
     zAcceleration           Acceleration OPTIONAL,
+    /** @details rollAngle
+    Roll angle of object from the ITS-S's reference point. For a vehicle, the angle is
+    reported in a body-fixed coordinate system as provided by ISO 8855 originating at the ITS-
station’s
+    reference point. For a RSU, the angle is reported in a coordinate system in which the y-
axis
+    corresponds to the North direction, the x-axis to the East direction, and the z- axis to
the vertical direction.
+    The angle is measured with positive values considering the object orientation turning
+    counter-clockwise around the x-axis.
+    */
+    rollAngle                CartesianAngle OPTIONAL,
+    /** @details pitchAngle
+    Pitch angle of object from the ITS-S's reference point. For a vehicle, the angle is
+    reported in a body-fixed coordinate system as provided by ISO 8855 originating at the ITS-
station’s
+    reference point. For a RSU, the angle is reported in a coordinate system in which the y-
axis
+    corresponds to the North direction, the x-axis to the East direction, and the z- axis to
the vertical direction.
+    The angle is measured with positive values considering the object orientation turning
+    counter-clockwise around the y-axis.
+    */
+    pitchAngle                CartesianAngle OPTIONAL,
     /** @details yawAngle
-    Relative yaw angle of object from the ITS-S's reference point. For a vehicle, the angle is
-    reported in a body-fixed coordinate system as provided by ISO 8855. For a RSU, the angle is
-    reported in a coordinate system in which the y-axis corresponds to the North direction, the
-    x-axis to the East direction, and the z- axis to the vertical direction.
+    Yaw angle of object from the ITS-S's reference point. For a vehicle, the angle is
+    reported in a body-fixed coordinate system as provided by ISO 8855 originating at the ITS-
station’s
+    reference point. For a RSU, the angle is reported in a coordinate system in which the y-
axis
```

```
+    corresponds to the North direction, the x-axis to the East direction, and the z- axis to
the vertical direction.
     The angle is measured with positive values considering the object orientation turning
-    counter-clockwise starting from the x-direction.
-    A value of 3601 shall be set if the value is unavailable.
-    The yaw angle confidence is described with a predefined confidence level of 95% for the
-    component.
+    counter-clockwise around the z-axis.
     */
     yawAngle                CartesianAngle OPTIONAL,
+    /** @details rollRate
+    Roll rate of object from the ITS-S's reference point. For a vehicle, the angular rate is
+    reported in a body-fixed coordinate system as provided by ISO 8855 originating at the ITS-
station's
+    reference point. For a RSU, the angular rate is reported in a coordinate system in which
the y-axis
+    corresponds to the North direction, the x-axis to the East direction, and the z- axis to
the vertical direction.
+   The angular rate is measured with positive values considering the object orientation turning
+    counter-clockwise around the x-axis.
+    */
+    rollRate                CartesianAngularSpeed OPTIONAL,
+    /** @details pitchRate
+    Pitch rate of object from the ITS-S's reference point. For a vehicle, the angular rate is
+    reported in a body-fixed coordinate system as provided by ISO 8855 originating at the ITS-
station's
+    reference point. For a RSU, the angular rate is reported in a coordinate system in which
the y-axis
+    corresponds to the North direction, the x-axis to the East direction, and the z- axis to
the vertical direction.
+   The angular rate is measured with positive values considering the object orientation turning
+    counter-clockwise around the y-axis.
+    */
+    pitchRate                CartesianAngularSpeed OPTIONAL,
+    /** @details yawRate
+    Yaw rate of object from the ITS-S's reference point. For a vehicle, the angular rate is
+    reported in a body-fixed coordinate system as provided by ISO 8855 originating at the ITS-
station's
+    reference point. For a RSU, the angular rate is reported in a coordinate system in which
the y-axis
+    corresponds to the North direction, the x-axis to the East direction, and the z- axis to
the vertical direction.
+   The angular rate is measured with positive values considering the object orientation turning
+    counter-clockwise around the z-axis.
+    */
+    yawRate                CartesianAngularSpeed OPTIONAL,
+    /** @details rollAcceleration
+    Roll acceleration of object from the ITS-S's reference point. For a vehicle, the angular
acceleration is
+    reported in a body-fixed coordinate system as provided by ISO 8855 originating at the ITS-
station's
+    reference point. For a RSU, the angular acceleration is reported in a coordinate system in
which the y-axis
+    corresponds to the North direction, the x-axis to the East direction, and the z- axis to
the vertical direction.
+   The angular acceleration is measured with positive values considering the object orientation
turning
+    counter-clockwise around the x-axis.
+    */
+    rollAcceleration                CartesianAngularAcceleration OPTIONAL,
+    /** @details pitchAcceleration
```

```
+    Pitch acceleration of object from the ITS-S's reference point. For a vehicle, the angular acceleration is
+    reported in a body-fixed coordinate system as provided by ISO 8855 originating at the ITS-station's
+    reference point. For a RSU, the angular acceleration is reported in a coordinate system in which the y-axis
+    corresponds to the North direction, the x-axis to the East direction, and the z- axis to the vertical direction.
+    The angular acceleration is measured with positive values considering the object orientation turning
+    counter-clockwise around the y-axis.
+    */
+    pitchAcceleration                CartesianAngularAcceleration OPTIONAL,
+    /** @details yawAcceleration
+    Yaw acceleration of object from the ITS-S's reference point. For a vehicle, the angular acceleration is
+    reported in a body-fixed coordinate system as provided by ISO 8855 originating at the ITS-station's
+    reference point. For a RSU, the angular acceleration is reported in a coordinate system in which the y-axis
+    corresponds to the North direction, the x-axis to the East direction, and the z- axis to the vertical direction.
+    The angular acceleration is measured with positive values considering the object orientation turning
+    counter-clockwise around the z-axis.
+    */
+    yawAcceleration                CartesianAngularAcceleration OPTIONAL,
+    /** @details lowerTriangularCorrelationMatrixColumns
+    Provides the columns of a lower triangular positive semi definite correlation matrix for the
+    kinematic state and attitude space provided for this object.
+    The order of the columns and rows of the correlation matrix is as follows:
+        - xDistance
+        - yDistance
+        - zDistance
+        - xSpeed
+        - ySpeed
+        - zSpeed
+        - xAcceleration
+        - yAcceleration
+        - zAcceleration
+        - rollAngle
+        - pitchAngle
+        - yawAngle
+        - rollRate
+        - pitchRate
+        - yawRate
+        - rollAcceleration
+        - pitchAcceleration
+        - yawAcceleration
+    The number of lowerTriangularCorrelationMatrixColumns to be included "k" is thereby the number of provided
+    values "n" of the kinematic state and attitude space minus 1: k = n-1.
+    Each column "i" of the lowerTriangularCorrelationMatrixColumns contains k-(i-1) values.
+    In case certain values of the kinematic state and attitude space are not provided, they are omitted from
+    the lowerTriangularCorrelationMatrixColumns.
+    */
+    lowerTriangularCorrelationMatrixColumns        LowerTriangularPositiveSemidefiniteMatrix OPTIONAL,
     /** @details planarObjectDimension1
     First dimension of object as provided by the sensor or environment model. This dimension is
```

```
     always contained in the plane which is oriented perpendicular to the direction of the angle
@@ -155,10 +255,18 @@ PerceivedObject ::= SEQUENCE {
     /** @details objectAge
     Provides the age of the detected and described object.
     */
-    objectAge               ObjectAge OPTIONAL,
+    objectAge               ObjectAge,
+    /** @details objectConfidence
+    The confidence associated to the object. The computation of the object confidence is based on a sensor's or
+    fusion system's specific detection confidence, the binary detection success that is, if an object
+    has been successfully detected by the last measurement and the object age.
+    */
+    objectConfidence        ObjectConfidence OPTIONAL,
     /** @details sensorIDList
     List of sensor-IDs which provided the measurement data. Refers to the sensorID in the
     @see SensorInformationContainer.
+     If the @see SensorInformationContainer is never provided by the disseminating ITS-S, the list shall be
+    populated with random numbers, where each number is assigned to a sensor of the transmitting station.
     */
     sensorIDList            SensorIdList OPTIONAL,
     /** @details dynamicStatus
```

Changes in CPM_CommonDataTypes.asn:

```
--- a/asn/CPM_CommonDataTypes.asn
+++ b/asn/CPM_CommonDataTypes.asn
@@ -180,7 +180,7 @@ ObjectDimension ::= SEQUENCE {
 }

 /** @brief Cartesian Angle
-A general Data Frame to describe an angular component along with a confidence with a predefined
+A general Data Frame to describe an angle component along with a confidence with a predefined
 confidence level of 95% for the component in a Cartesian coordinate system.
 */
 CartesianAngle ::= SEQUENCE {
@@ -195,6 +195,38 @@ CartesianAngle ::= SEQUENCE {
     confidence  AngleConfidence
 }

+/** @brief CartesianAngularSpeed
+A general Data Frame to describe an angular speed component along with a confidence with a predefined
+confidence level of 95% for the component in a Cartesian coordinate system.
+*/
+CartesianAngularSpeed ::= SEQUENCE {
+    /** @details value
+   The angular speed (rate) value which can be estimated as the mean of the current distribution.
+    */
+    value       CartesianAngularSpeedValue,
+    /** @details confidence
+    The accuracy associated to the provided value at a predefined confidence level
+    of 95% for the component.
+    */
+    confidence  AngularSpeedConfidence
+}
```

```
+
+/** @brief CartesianAngularAcceleration
+A general Data Frame to describe an angular acceleration component along with a confidence with a predefined
+confidence level of 95% for the component in a Cartesian coordinate system.
+*/
+CartesianAngularAcceleration ::= SEQUENCE {
+    /** @details value
+   The angular acceleration value which can be estimated as the mean of the current distribution.
+    */
+    value       CartesianAngularAccelerationValue,
+    /** @details confidence
+    The accuracy associated to the provided value at a predefined confidence level
+    of 95% for the component.
+    */
+    confidence  AngularAccelerationConfidence
+}
+
 /** @brief WGS 84 Angle
 A general Data Frame to describe an angular component along with a confidence with a predefined
 confidence level of 95% for the component in the WGS84 coordinate system.
@@ -315,6 +347,32 @@ MessageSegmentInfo ::= SEQUENCE {
     thisSegmentNum      SegmentCount
 }

+/** @brief Lower Triangular Positive Semi-Definite Matrix
+A general data frame to express the elements of a lower triangular positive semi-definite matrix, not
+including the main diagonal elements of the matrix.
+Given a matrix "A" of size n x n, the number of columns to be included in the lower triangular matrix is k=n-1.
+*/
+LowerTriangularPositiveSemidefiniteMatrix ::= SEQUENCE SIZE (1..17) OF CorrelationColumn
+
+/** @brief Correlation Column
+The column of the lower triangular positive semi-definite matrix consists of correlation row values.
+Given a matrix "A" of size n x n, the number of columns to be included in the lower triangular matrix is k=n-1.
+Each column "i" of the lower triangular then contains k-(i-1) values, where "i" refers to the column number count
+starting at 1 from the left.
+*/
+CorrelationColumn ::= SEQUENCE SIZE (1..17) OF CorrelationRowValue
+
+/** @brief Correlation Row Value
+The Bravais-Pearson correlation value for each cell of the lower triangular correlation matrix.
+Scaled by 100.
+@unit: None
+*/
+CorrelationRowValue ::= INTEGER {
+    full-negative-correlation    (-100),     -- Full negative correlation
+    no-correlation               (0),        -- If not correlated or unavailable
+    point-one                    (10),
+    full-positive-correlation    (100)       -- Full positive correlation
+
 /** @brief Object Class Description
 A list of object classes.
 */
```

```
@@ -326,9 +384,7 @@ categories: vehicle, person, animal and other. The classification is provided wi
 confidence indication.
 */
 ObjectClassWithConfidence ::= SEQUENCE {
-    -- @todo
     objectClass ObjectClass,
-    -- @todo
     confidence  ClassConfidence
 }

@@ -366,8 +422,6 @@ NodeOffsetPointZ ::= CHOICE {
     node-Z6 Offset-B16  -- node is within 327.67m of last node
 }

-
-
 /** @brief Animal Subclass Type
 Describes the subclass of a detected object for class animal.
 @unit n/a
@@ -462,7 +516,7 @@ WGS84AngleValue ::= INTEGER {
 } (0..3601)

 /** @brief Cartesian Angle Value
-An angle value in degrees described in a local Cartesian coordinate system, counted positive in
+An angle value described in a local Cartesian coordinate system, counted positive in
 a right-hand local coordinate system from the abscissa.
 @unit 0,1 degrees
 */
@@ -472,20 +526,80 @@ CartesianAngleValue ::= INTEGER {
     unavailable         (3601)
 } (0..3601)

+/** @brief Cartesian Angular Speed Value
+An angular speed value described in a local Cartesian coordinate system, counted positive in
+a right-hand local coordinate system from the abscissa.
+@unit 0,01 degrees/s
+*/
+CartesianAngularSpeedValue ::= INTEGER {
+    noSpeed                            (0),
+    oneDegreePerSecondAntiClockwise     (100),
+    oneDegreePerSecondClockwise         (-100)
+} (-32766..32767)
+
+/** @brief Cartesian Angular Acceleration Value
+An angular acceleration value described in a local Cartesian coordinate system, counted positive in
+a right-hand local coordinate system from the abscissa.
+@unit 0,01 degrees/s^2 (degrees per second squared)
+*/
+CartesianAngularAccelerationValue ::= INTEGER {
+    noAcceleration                            (0),
+    oneDegreePerSecondSquaredAntiClockwise     (100),
+    oneDegreePerSecondSquaredClockwise         (-100)
+} (-32766..32767)
+
+
 /** @brief Angle Confidence
 The absolute accuracy of a reported angle value for a predefined confidence level (e.g. 95 %).
```

```
 The required confidence level is defined by the corresponding standards applying this DE.
 @unit 0,1 degrees
 */
 AngleConfidence ::= INTEGER {
-    zeroPointOneDegree  (1),    -- if the heading accuracy is equal to or less than 0,1 degree
+    zeroPointOneDegree  (1),
     oneDegree           (10),
-    outOfRange          (126),  -- if the heading accuracy is out of range, i.e. greater than
+    outOfRange          (126),  -- if the  accuracy is out of range, i.e. greater than
                                -- 12,5 degrees. A corresponding reported angle value shall be
                                -- considered invalid and cannot be trusted.
-    unavailable         (127)   -- if the heading accuracy information is not available
+    unavailable         (127)   -- if the accuracy information is not available
 } (1..127)

+/** @brief Angular Speed Confidence
+The absolute accuracy of a reported angular speed value for a predefined confidence level (e.g.
95 %).
+The required confidence level is defined by the corresponding standards applying this DE.
+For correlation computation, maximum interval levels shall be assumed.
+@ n/a
+*/
+AngularSpeedConfidence ::= ENUMERATED {
+    degSec-000-01 (0),  -- if the accuracy is equal to or less than 0,01 degree/second
+    degSec-000-05 (1),  -- 1 if the accuracy is equal to or less than 0,05 degrees/second
+    degSec-000-10 (2),  -- if the accuracy is equal to or less than 0,1 degree/second
+    degSec-001-00 (3),  -- 3 if the accuracy is equal to or less than 1 degree/second
+    degSec-005-00 (4),  -- if the accuracy is equal to or less than 5 degrees/second
+    degSec-010-00 (5),  -- if the accuracy is equal to or less than 10 degrees/second
+    degSec-100-00 (6),  -- if the accuracy is equal to or less than 100 degrees/second
+    outOfRange (7),     -- if the accuracy is out of range, i.e. greater than 100 degrees/second
+    unavailable (8)     -- if the accuracy information is unavailable
+}
+
+/** @brief Angular Acceleration Confidence
+The absolute accuracy of a reported angular acceleration value for a predefined confidence level
(e.g. 95 %).
+The required confidence level is defined by the corresponding standards applying this DE.
+For correlation computation, maximum interval levels shall be assumed.
+@ n/a
+*/
+AngularAccelerationConfidence ::= ENUMERATED {
+    degSecSquared-000-01 (0),  -- if the accuracy is equal to or less than 0,01 degree/second^2
+    degSecSquared-000-05 (1),  -- 1 if the accuracy is equal to or less than 0,05 degrees/second^2
+    degSecSquared-000-10 (2),  -- if the accuracy is equal to or less than 0,1 degree/second^2
+    degSecSquared-001-00 (3),  -- 3 if the accuracy is equal to or less than 1 degree/second^2
+    degSecSquared-005-00 (4),  -- if the accuracy is equal to or less than 5 degrees/second^2
+    degSecSquared-010-00 (5),  -- if the accuracy is equal to or less than 10 degrees/second^2
+    degSecSquared-100-00 (6),  -- if the accuracy is equal to or less than 100 degrees/second^2
+    outOfRange (7),     -- if the accuracy is out of range, i.e. greater than 100 degrees/second^2
+    unavailable (8)     -- if the accuracy information is unavailable
+}
+
+
 /** @brief Semi Range Length
 The length of an axis of an ellipsoid or rectangle, used to describe the extension in a
 particular direction.
@@ -595,16 +709,16 @@ ObjectAge ::= INTEGER {
 } (0..1500)
```

```
 /** @brief Object Confidence
-The confidence in the existence of the object and its characteristics as indicated by the
-@see PerceivedObject container.
+A single-value indication about the overall information quality of a perceived object. Its
computation
+is based on several scaling factors and moving averages. See Clause 7.6.4 of ETSI TS 103 324
for details
+on the computation.
 @unit n/a
 */
 ObjectConfidence ::= INTEGER {
-    unknown             (0),    -- Object confidence is unknown
-    onePercent          (1),
-    oneHundredPercent   (100),
-    unavailable         (101)   -- Confidence could not be computed and does not apply
-} (0..101)
+    noConfidence        (0),    -- No confidence in detected object, e.g. for "ghost"-objects
or
+                                -- if confidence could not be computed
+    fullConfidence      (15)    -- Full confidence in detected object
+} (0..15)

 /** @brief Object Dimension Value
 A dimension for an object.
```

4 Representation of object confidence

The second key research question for the investigation study focused on how an object's confidence shall be best represented in CPM.

This chapter provides insights to this work and its results. At first, the initial considerations are presented, thereafter the simulation and evaluation methodology is described before finally showing the key findings and results. In the last section the resulting proposed changes to ETSI 103 324 are given.

4.1 Considerations

4.1.1 Requirements for object confidence

After having determined the concrete definition of terms and the separate consideration of accuracy and existence probability, the generic requirements for object confidence need to be collected. The following lists represents the summary of this collection:

- Provision of a generic indication of the quality of an object through a single value
- The metric shall be applicable for both vehicles and infrastructure (i.e. for ITS stations with many and few sensors alike)
- Computation of the metric shall not be too complex
- The metric needs to cope with the fact that object detection is OEM- and sensor-specific
- Nevertheless, the resulting value shall give a proper and harmonized representation of the actual confidence on the object's existence

In addition to these generic requirements on the metric for object confidence, a set of object characteristics was chosen, which should contribute to / have an impact on the overall confidence value. This set of characteristics is presented in the following section.

4.1.2 Relevant input parameters

Based on the requirements worked out in the previous subsection, relevant input parameters for object confidence where determined. For every CPM, the following parameters shall contribute to the object confidence:

- Object age
- Sensor or system specific detection confidence
- Detection success

As previously determined (see chapter 2.2), object accuracy and confidence are two separate concepts, therefore accuracy is not considered here.

These considered input parameters base on the assumption that any detection system (or single sensor) has its individual measures to provide an indication of the confidence and to judge whether an object is actually detected. Those system specific assessments are the input for the object quality concept.

Initially, the count of sensors detecting the object was also considered relevant for the object confidence. Taking also the number of detecting sensors into account would have resulted in the "discrimination" of ITS stations, even when considering different options:

1. Inclusion of the absolute number of detecting sensors

   This option discriminates ITS stations with only few sensors. This means that an ITS station with only one sensor could never achieve a full object confidence rating even if the detection of this one sensor is very good and reliable. Moreover, the range of available sensors per ITS station differs largely from vehicles possibly only having one sensor to infrastructures at intersections potentially having more than 20 sensors.

2. Inclusion of the relative portion of detecting sensors

   This option is more complex to implement and could discriminate ITS stations with many sensors. In this case, ITS stations having only one sensor always achieve a full individual rating for the count of sensors whereas stations having 3 sensors or more, of which only individual sensors detect the object could not reach the full individual rating even though they have more detecting sensors of potentially equal or higher reliability.

For all the above mentioned reasons the count of detecting sensors is not included as an input parameter for object confidence.

4.1.3 Starting concept

As the requirement of having a metric with low computational complexity had a high priority (otherwise transmitting stations might omit the object confidence altogether), the basic concept of a sliding window in combination with a rating system was chosen.

The general process is as follows:

1. Compute a moving average for system specific confidence and detection success
2. Scale each of the two averages to a value range of 0..10 to obtain individual ratings
3. Compute the rating for object age
4. Compute a weighted average of the three ratings to obtain the overall object confidence

The general concept for these three steps is explained in more detail in the following.

Moving average and scaling

The first concept builds on a simple moving average using a sliding window. This concept lead to more open questions such as how to choose the sliding window (size and "frequency") and how the different, discrete values in the sliding window should be weighted.

Therefore, instead of a sliding window, the exponential moving average (EMA) was chosen, which, due to its iterative nature, has less configuration complexity.

Input: Series of data D , where $\forall\, d \in D: 0 \leq d \leq 1$

Parameter: Weighting factor $\alpha, 0 \leq \alpha \leq 1$, (the larger α, the faster the influence of "old" data decreases)

Process:

1) Resulting exponential moving average

$$EMA_0 = D_0\,,\ \ EMA_t = \alpha * D_t + (1-\alpha) * EMA_{t-1}\ for\ t \in \mathbb{N}, t > 0$$

2) Rating (scaling to a value range 0..10)

$$r = \lfloor EMA_t * 10 \rfloor$$

As a result of this process, one obtains the ratings r_c for the specific confidence and r_d for the detection success.

Rating for object age

For object age, a moving average isn't suitable, rather a stepwise rating shall be used. The object age in CPM has a value range of 0..1500 ms. Therefore, the rating is defined in steps of 150 ms as follows:

Input: Object age OA

Process:

3) Rating $r_{oa} = \min\{\lfloor OA/150 \rfloor, 10\}$

Object confidence as weighted average

Input: Individual ratings r_d, r_c und r_{oa} for detection, confidence and object age

Parameters: Weighting factors w_d, w_c and w_{oa} for the individual ratings

Process: Resulting object confidence

$$OC = \left\lfloor \frac{w_d * r_d + w_c * r_c + w_{oa} * r_{oa}}{w_d + w_c + w_{oa}} \right\rfloor$$

4.2 Methodology

This concept for object confidence was also investigated in the simulation study. The general setup is the same as described in chapter 3.2. For the object confidence concept described above a system specific confidence is required as input parameter. As the SceneSuite doesn't provide this information, a detection probability scaled linearly over the length of the sensor's FOV is implemented. The minimum and maximum expectation for the detection probability is configurable. This value is used as the expectation for a normal distribution (with variance again configurable) to obtain the detection confidence per measurement.

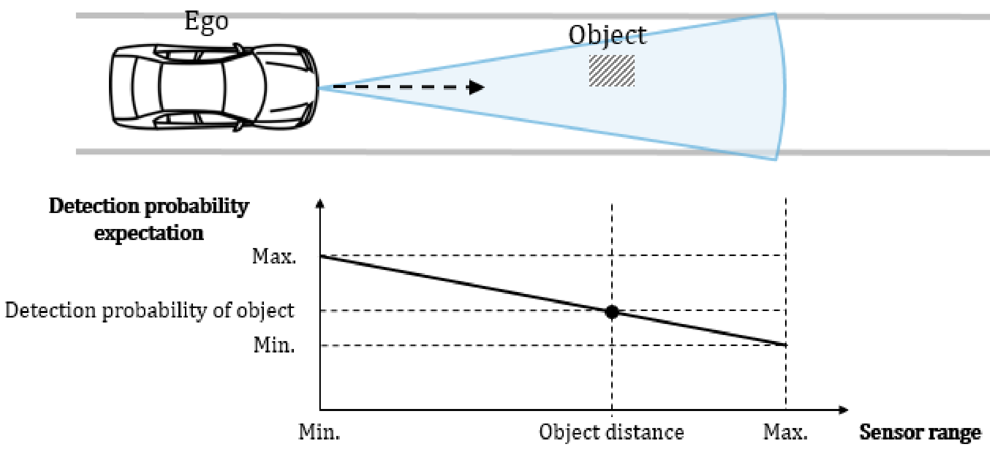


Figure 15: Expectation of the detection probability

For the evaluation, all input parameters for object confidence (system specific confidence, detection losses and object age) as well as the resulting object confidence are plotted for individual simulations runs over time. The following chapter provides some insights to the results.

4.3 Findings and resulting concept

The concept for object confidence determination provides several configuration options: the weighting factor α for the exponential moving average and the weights w_d, w_c and w_{oa} for the individual ratings. The decision how to best configure these factors will need to be done in later profiling. The plots shown below were all created with a configuration, where $w_d = w_c = w_{oa}$.

Figure 16 Shows all input parameters: system specific confidence with corresponding detection losses in the upper plot (detection losses created through a confidence limit), the corresponding object age in the middle plot and all ratings as described in the concept in the lower plot.

With all weighting factors for the different individual ratings being equal, the resulting object confidence is rather reactive to changes in the confidence and detection ratings. Using a larger weighting factor for the object age in this case would result in a smoothened object confidence – but this would also mean that a newly detected object would always have a quite low object confidence even if the system specific confidence was very high.

In Figure 17 and Figure 18 different EMA factors are used to better understand the impact. As explained earlier, a higher scaling factor α causes the impact of old data to decrease faster. This also leads to the resulting ratings being more "reactive" to new data. This can be seen in the two plots. Using the lower scaling factor of 0.2 smoothens the ratings. On the other hand, this again reduces the object confidence for newly detected objects.

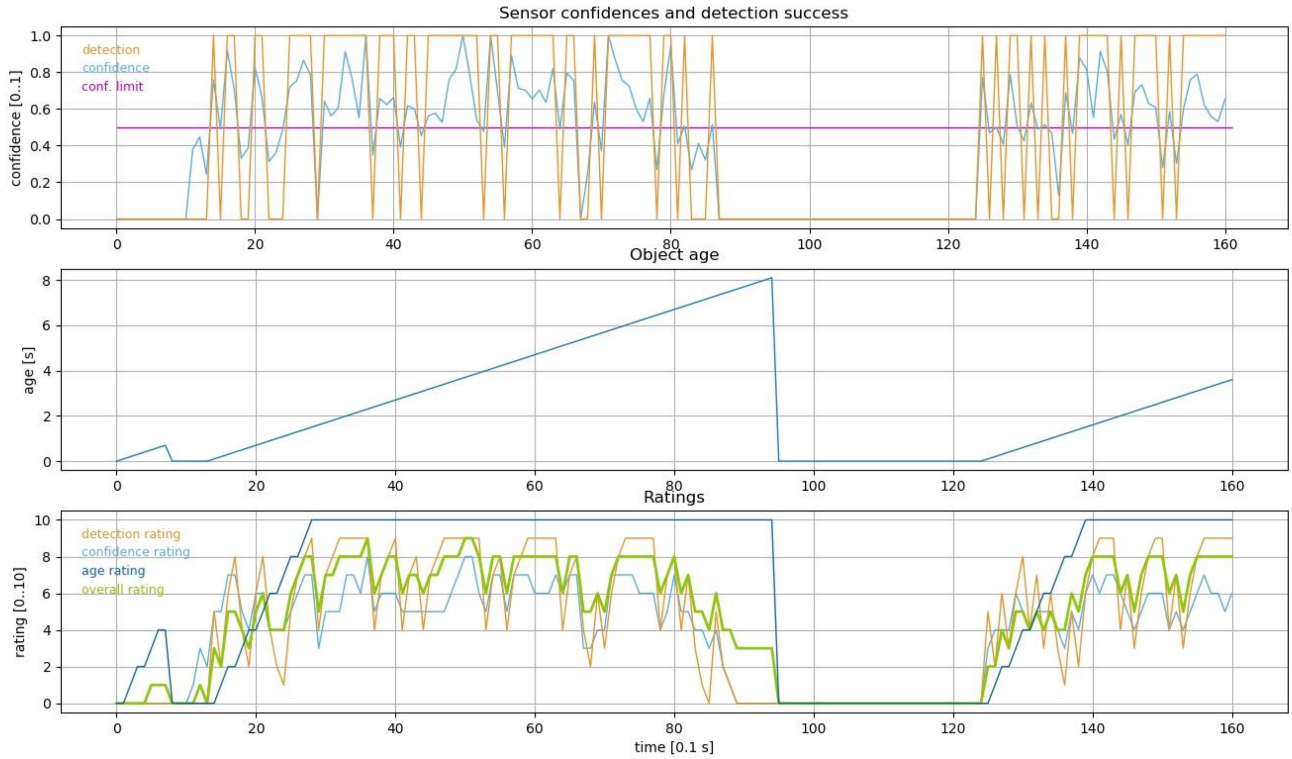


Figure 16: System specific confidence and detection losses, object age and ratings

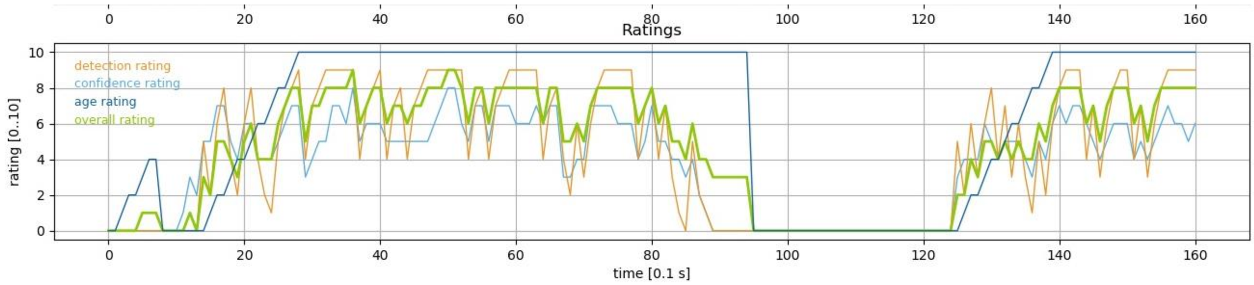


Figure 17: EMA scaling factor α = 0.5

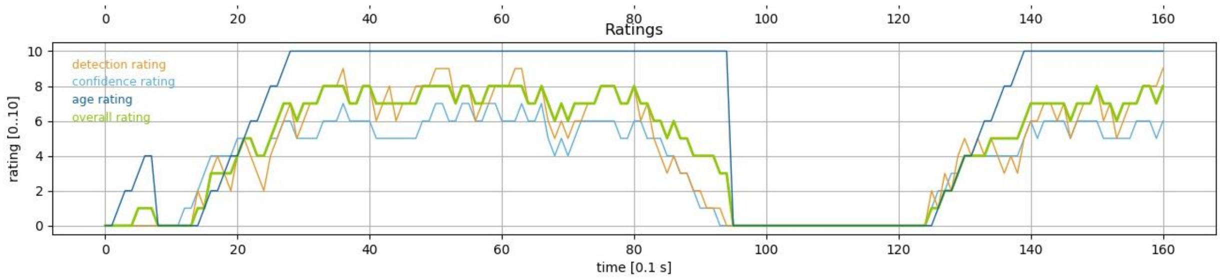


Figure 18: EMA scaling factor α = 0.2

In general the concept for object confidence seems to be suitable for the purpose of providing a one-valued indication of an object's "quality". In contrast to initial considerations, object confidence will not be used as the single one most relevant information of how reliable a provided object is – it may rather serve as indication to be compared against a configurable threshold.

Therefore, the concept as described in 4.1.3 shall be proposed to ETSI. Only change to be made compared to the starting concept is that the ratings shall not be scaled in the value range 0..10 but in the range 0..15 to make full use of the 4 bits value range.

The following chapter provides the full proposal to be made to ETSI for object confidence.

4.4 Contribution to ETSI TS 103 324

In addition to the proposal made for object accuracy, the C2C-CC proposes a further extension of clause 7.6. of ETSI TS 103 324 as follows:

7.6 Perceived Object Container

<see proposal for object accuracy> - Continuation

The age of the detected object shall be provided for each object. The *objectAge* shall reflect the time how long the object is already known to the sender's system at the time of message generation.

7.6.4 Object confidence

A one-value indication about the overall information quality on a perceived object may be provided through the *objectConfidence*. The determination of this value is described in the following.

7.6.4.1 Components of object confidence

The object characteristics contributing to the object confidence are

1) Object age
2) Sensor or system specific detection confidence
3) Detection success

The object age referred here corresponds to the value of *objectAge* as provided in CPM, whereas the detection confidence and the detection success indication are system specific assessments of the current object detection. “Detection success” describes the assessment whether a given measurement has successfully perceived the object (binary assessment).

7.6.4.2 Object confidence representation

The *objectConfidence* at a discrete time instant *t*, if provided, shall be determined according to the following process:

1) Compute the exponential moving average for the system specific confidence c with factor $\alpha, 0 \leq \alpha \leq 1$,
   a. If $t == 0$: $EMA_0 = c_0$
   b. If $t > 0$: $EMA_t = \alpha * D_t + (1 - \alpha) * EMA_{t-1}$
2) Compute the rating $r_c = floor(EMA_t * 15)$
3) Repeat steps 1) and 2) for the detection success d to obtain rating r_d
4) Compute the object age rating $r_{oa} = \min\{\lfloor OA/100 \rfloor, 15\}$
5) Compute object confidence $objectConfidence = floor(\frac{w_d * r_d + w_c * r_c + w_{oa} * r_{oa}}{w_d + w_c + w_{oa}})$ with weights w_d, w_c and w_{oa}

The specification of factor α and weights w_d, w_c and w_{oa} is out of scope of this document and left open for profiling.

For the encoding in ASN.1 the C2C-CC proposes the following:

CommonDataTypes.asn [Note: This change has already been included in the list of ASN.1 changes in Section 3.4 of this document. The changes specifically related to objectAge and objectConfidence are stated here again for reference]:

```
--- a/asn/CPM_CommonDataTypes.asn
+++ b/asn/CPM_CommonDataTypes.asn
@@ -595,16 +709,16 @@ ObjectAge ::= INTEGER {
 } (0..1500)

 /** @brief Object Confidence
-The confidence in the existence of the object and its characteristics as indicated by the
-@see PerceivedObject container.
+A single-value indication about the overall information quality of a perceived object. Its
computation
```

```
+is based on several scaling factors and moving averages. See Clause 7.6.4 of ETSI TS 103 324
for details
+on the computation.
 @unit n/a
 */
 ObjectConfidence ::= INTEGER {
-    unknown             (0),    -- Object confidence is unknown
-    onePercent          (1),
-    oneHundredPercent   (100),
-    unavailable         (101)   -- Confidence could not be computed and does not apply
-} (0..101)
+    noConfidence        (0),    -- No confidence in detected object, e.g. for "ghost"-objects
or
+                                -- if confidence could not be computed
+    fullConfidence      (15)    -- Full confidence in detected object
+} (0..15)

 /** @brief Object Dimension Value
 A dimension for an object.
```

Changes in PerceivedObject.asn. Notice that objectAge has to become mandatory for the correct interpretation of the objectConfidence. [Note: This change has already been included in the list of ASN.1 changes in Section 3.4 of this document. The changes specifically related to objectAge and objectConfidence are stated here again for reference]

```
--- a/asn/PerceivedObject.asn
+++ b/asn/PerceivedObject.asn
@@ -155,10 +255,18 @@ PerceivedObject ::= SEQUENCE {
     /** @details objectAge
     Provides the age of the detected and described object.
     */
-    objectAge               ObjectAge OPTIONAL,
+    objectAge               ObjectAge,
+    /** @details objectConfidence
+    The confidence associated to the object. The computation of the object confidence is based
on a sensor's or
+    fusion system's specific detection confidence, the binary detection success that is, if an
object
+    has been successfully detected by the last measurement and the object age.
+    */
+    objectConfidence        ObjectConfidence,
     /** @details sensorIDList
     List of sensor-IDs which provided the measurement data. Refers to the sensorID in the
     @see SensorInformationContainer.
+     If the @see SensorInformationContainer is never provided by the disseminating ITS-S, the
list shall be
+    populated with random numbers, where each number is assigned to a sensor of the transmitting
station.
     */
     sensorIDList            SensorIdList OPTIONAL,
     /** @details dynamicStatus
```

5 Other changes and input to future profiles

The following list is to be considered as a list of open points which possibly should be considered in later profiling of the CPM

- Specify if and how the standard deviation an correlation shall be scaled to a 95% confidence level
- Specify the usage of the sensor id list even without SensorInformationContainer to indicate number of detecting sensors (with dummy IDs)
  This requires the adaptation of the description for the SensorIDList in the PerceivedObject.asn file:

```
--- a/asn/PerceivedObject.asn
+++ b/asn/PerceivedObject.asn
@@ -161,6 +161,8 @@ PerceivedObject ::= SEQUENCE {
     /** @details sensorIDList
     List of sensor-IDs which provided the measurement data. Refers to the sensorID in
the
     @see SensorInformationContainer.
+    If the @see SensorInformationContainer is never provided by the disseminating ITS-
S, the list shall be
+     populated with random numbers, where each number is assigned to a sensor of the
transmitting station.
     */
     sensorIDList            SensorIdList OPTIONAL,
     /** @details dynamicStatus
--
```

- Profiling of the EMA factor to apply in the computation of the object confidence
- Profiling of the weighting factors for the components of the object confidence

6 Appendix 1 – References

6.1 List of abbreviations

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistant System
COM	Communication
CPM	Collective Perception Message
EC	European Commission
EDAS	EGNOS Data Access System
EGNOS	European Geostationary Navigation Overlay Service
EMA	Exponential Moving Average
ESA	European Space Agency
ESP	Elektronic Stability Programme
EU	European Union
FCD	Floating Car Data
FhG	Fraunhofer Gesellschaft
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HMI	Human Machine Interface
ITS	Intelligent Transport System
LBS	Location Based Services
OEM	Original Equipment Manufacturer
PDA	Personal Digital Assistant
UMTS	Universal Mobile Telecommunications System
WLAN	Wireless Local Area Network

6.2 Applicable documents

[AD-1] DIN/ISO 5725-1:1997, „Accuracy (trueness and precision of measurement methods and results – Part 1: General principles and definitions)“

[AD-2] ISO/IEC 25012:2008, “Software engineering – Software product Quality Requirements and Evaluation (SQuaRE) – Data quality model

[AD-3] ISO 3534-1:2006, “Statistics – Vocabulary and symbols – Part 1: General statistical terms and terms used in probability

[AD-4] https://www.ipb.uni-bonn.de/pdfs/Forstner1999Metric.pdf, last visited on 14.01.2021

[AD-5] https://maitra.public.iastate.edu/stat501/lectures/InferenceForMeans-Confidence.pdf, last visited on 14.01.2021

[AD-6] http://mathworld.wolfram.com/Covariance.html, last visited on 14.01.2021

[AD-7] ETSI EN 302 890-2 V2.1.1 (2020-10) (https://www.etsi.org/deliver/etsi_en/302800_302899/30289002/02.01.01_20/en_30289002v020101a.pdf).

6.3 Related documents

[RD-1] LiteratureOverview.pdf (work result of F0014)

■ End of Document ■