SLOVENSKI STANDARD
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Vesolje - Uporaba sistemov globalne satelitske navigacije (GNSS) za ugotavljanje položaja pri inteligentnih transportnih sistemih (ITS) v cestnem prometu - Podrobna opredelitev meritev in ravni uspešnosti

Space - Use of GNSS-based positioning for road Intelligent Transport Systems (ITS) - Metrics and Performance levels detailed definition

Detaillierte Definition von Metriken und Leistungsstufen

Espace - Utilisation de la localisation basée sur les GNSS pour les systèmes de transport routiers intelligents - Définition détaillée des mesures et niveaux de performance

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35.240.60	Uporabniške rešitve IT v prometu	IT applications in transport

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Detaillierte Definition von Metriken und Leistungsstufen

This Technical Report was approved by CEN on 13 January 2020. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

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European foreword

This document (CEN/TR 17448:2020) has been prepared by Technical Committee CEN/JTC 5 “Space”, the secretariat of which is held by DIN.

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1 Scope

This document constitutes the main deliverable from WP1.1 of the GP-START project. It is devoted to a thorough review of the metrics defined in EN 16803-1 and proposes a performance classification for GNSS-based positioning terminals within designed for road applications. It will serve as one of the inputs to the elaboration of prEN 16803-2:2019 and prEN 16803-3:2019.

This document should serve as a starting point for discussion within CEN/CENELEC/JTC 5/WG1 on a consolidated set of performance metrics and associated classification logic. The proposals and conclusions appearing in this document are therefore only preliminary.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 16803-1:2016, *Space - Use of GNSS-based positioning for road Intelligent Transport Systems (ITS) - Part 1: Definitions and system engineering procedures for the establishment and assessment of performances*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 16803-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 List of acronyms

ADAS	Advanced Driver Assistance Systems
CAN	Controller Area Network
CDF	Cumulative Distribution Function
CEN	Comité Européen de Normalization — (*European Committee for Standardization*)
CENELEC	Comité Européen de Normalization Électrotechnique — (*European Committee for Electrotechnical Standardization*)
ECEF	Earth Centred Earth Fixed
ETSI	European Telecommunications Standards Institute
GBPT	GNSS-Based Positioning Terminal
GNSS	Global Navigation Satellite Systems
HPA	Horizontal Position Error
HPL	Horizontal Protection Level
IMU	Inertial Measurement Unit
ITS	Intelligent Transport Systems
KOM	Kick-Off Meeting
MEMS	Micro Electro-Mechanical Systems

NMEA	National Marine Electronics Association
PPP	Precise Point Positioning
RTCA	Radio Technical Commission for Aeronautics
RTK	Real Time Kinematics
SPP	Standard Point Positioning
TTFF	Time To First Fix

5 Review of EN 16803-1 Performance Metrics

5.1 Potential Improvements of unstable definitions

5.1.1 Position accuracy metrics

5.1.1.1 Vectors vs their Norms

One thing that draws immediate attention when reviewing the metrics is some degree of ambiguity in some of the definitions. For instance, the first Accuracy metric (EN 16803-1:2016, Table 1) refers to the "3D position error", which has not been explicitly defined anywhere along the document:

3D Position Accuracy is defined as the set of three statistical values given by the 50th, 75th and 95th percentiles of the cumulative distribution of 3D position errors.

There is some discussion in EN 16803-1:2016, 3.2.1 regarding vector and scalar quantities, but no explicit definition of the 3D position error is proposed. The position error (without the "3D" adjective) is defined in EN 16803-1:2016, 4.3 as follows:

Position error: is the difference between the true position and the position provided by the positioning terminal. It shall be understood as a vector expressed in some convenient local reference frame (e.g. local horizontal frame).

This definition explicitly states that the position error shall be understood as a vector quantity. Then, the use of the expression "3D position error" in the definition of the metric seems to emphasize the vector character of the position error, which may be misleading since the metric actually refers to the norm of the position error vector, which is actually a scalar quantity.

The same concern can be raised about the horizontal position error. It is therefore recommended to include explanations on the meaning of expressions such as "3D position error" and "horizontal position error", making it clear that they refer to norms of vectors rather than vectors. Note that footnote 5 on EN 16803-1:2016, A.2.1 of the document contains such a clarification for the case of the horizontal position error, but a footnote in an annex may not be the best place for it (besides, the expression "it is recalled" seems to indicate that the definition was written in some other, more prominent place within the document and later removed).

NOTE The norm of a vector is not uniquely defined. To overcome this problem, it could be further specified that the norm of interest is the Euclidean norm (square root of the sum of squared coordinates) of the vector when expressed in a linear (and orthonormal) coordinate system. Suppose, for instance, that the position is expressed in geodetic coordinates (latitude, longitude and height) and the position error is expressed as a latitude error, a longitude error and a height error. The square root of the sum of the squares of these 3 quantities has no physical meaning, and is not what is meant in the above proposed definition. It could be worth making this sort of considerations in the standard.

A related remark (although not concerned with performance metrics) is on the identification of the GBPT outputs made in EN 16803-1:2016, 4.2, which may require some review and perhaps include attitude parameters (e.g. heading) or make some additional considerations on the reference frame used to represent position and velocity (e.g. horizontal velocity could be represented in polar coordinates as a pair consisting of speed and heading).

5.1.1.2 Along Track and Cross Track Components

Another potential issue that has been detected is the fact that the expressions “along track” and “cross track” are undefined, yielding the definitions of “*along track*” and “*cross track*” position accuracy a little ambiguous. It is recommended to include the definitions of these terms somewhere in the document, especially considering that there is no general agreement as to their meanings. Note that these terms have their roots in aeronautics and astronautics, and have been widely use to describe the motion of space vehicles, such as artificial satellites, especially when in orbit around the Earth. Each satellite is assigned a body-centred orthogonal reference frame with axes pointing:

— in the satellite’s direction of motion;

— in the direction orthogonal to the orbital plane;

— in the direction orthogonal to the previous 2.

However, since most orbits are nearly circular, the third direction is roughly pointing to the centre of the Earth, and in some cases, this is how the third axis is defined, implying a slight misalignment of the first with respect to the satellite’s direction of motion. Besides, the direction of motion is not well defined unless the satellite’s trajectory is referred to an external (not body-centred) reference frame, such as one with origin at the centre of the Earth. Depending on how this external frame is chosen (e.g. an inertial frame vs one which rotates with the Earth), the satellite’s direction of motion may be different.

In road applications the situation is also somewhat complicated. It may seem natural to define the along track direction as the one parallel to the vehicle’s velocity vector, but caution shall be taken as to the reference frame used to define the vehicle’s motion. A natural choice would be an Earth-centred, Earth-fixed (ECEF) frame, such as WGS84. Of course, when the vehicle is standing still, the along track direction is not well defined using the velocity vector (which in this case is the null vector), but still the last along track direction computed before the vehicle stopped could be used (besides, there is no actual “track” when the vehicle is not moving, so the along track and cross track errors may not make much sense in that case either). However, there is still the problem of defining the cross-track direction, and now there is no such thing as an orbital plane. Among all directions orthogonal to the along track axis, a natural choice seems to be the one lying on the horizontal plane (well defined unless the vehicle’s motion is purely vertical, which is an extremely unlikely situation in road applications). Another natural option seems to be the one lying on the local road plane, which may differ from the horizontal plane due to road banking. This second option may be of interest when an inertial measurement unit (IMU) is involved in the navigation process, as the local road plane is nearly fixed with respect to the IMU axes. However, the first option seems better for most implementations as it does not require any prior knowledge of the road geometry or of the vehicle’s attitude. There’s yet a third option to be considered in which the cross-track direction is the one defined by the normal acceleration vector, but this has an important drawback, namely that the normal acceleration is nearly zero when in low-dynamics situations (such as driving along a nearly straight road or a highway). Hence the first option continues to seem the most convenient one. With this in mind, the following definition is proposed:

Along track and cross track components are coordinates in a reference frame whose definition is based on the vehicle’s true velocity vector $\vec{v}$ (relative to some ECEF reference frame) and the local upward unit vector $\vec{\eta}$. Namely, the said reference frame is defined by the following 3 orthogonal unit vectors: $\vec{\tau} = \vec{v} / \|\vec{v}\|$, $\vec{n} = \vec{\eta} \times \vec{v} / \|\vec{\eta} \times \vec{v}\|$ and $\vec{b} = \vec{\tau} \times \vec{n}$. The along track and cross track components of a vector $\vec{\varepsilon}$ attached to the user’s position (such as the position error vector) are then defined as the scalar products $\vec{\varepsilon} \cdot \vec{\tau}$ and $\vec{\varepsilon} \cdot \vec{n}$, respectively.

NOTE 1 The vector $\vec{n}$ as defined above corresponds to the first of the 3 options previously discussed: it is orthogonal to the along track direction (given by $\vec{v}$) and lies on the horizontal plane (as it is orthogonal to $\vec{\eta}$).

NOTE 2 The notation used to define the reference frame is commonly used to denote the so-called Frenet trihedron, although the reference frame defined above and the Frenet trihedron are not exactly the same (rather, the Frenet trihedron would correspond to the third option, which has been readily discarded).

5.1.2 Velocity Accuracy Metrics

The same considerations made in 5.1.1 with regard to position accuracy metrics can be directly applied to velocity accuracy metrics, in particular those regarding the ambiguity in the use of expressions such as 3D or horizontal, along track and cross track, etc. Also, identical recommendations are made and analogous rewordings are proposed.

In addition, it has been pointed out that 3D and horizontal velocity accuracy metrics may not be relevant and could be deleted. It has also been pointed out that there may be some redundancy between 3D velocity accuracy and speed accuracy. At this point it is worth discussing the difference between both.

Suppose that the true velocity vector (expressed in some orthonormal coordinate system, such as the local horizontal system with coordinates along the East, North and up axes) is $\vec{v}_t = (1,0,0)$ and that the estimated velocity is $\vec{v}_e = (-1,0,0)$. Then the speed error would be $\left\|\vec{v}_e\| - \|\vec{v}_t\|\right| = |1-1| = 0$, whereas the 3D velocity error (in norm) would be $\|\vec{v}_e - \vec{v}_t\| = \|(-2,0,0)\| = 2$, thus illustrating the difference between both concepts. The underlying idea is that the norm of the error is not the same thing as the error of the norm, which is a consequence of the Triangle Inequality illustrated in Figure 1. Speed accuracy refers to the error of the norm, whereas 3D velocity accuracy refers to the norm of the error, so this shows that 3D Velocity and Speed metrics proposed in EN 16803-1 are not redundant.

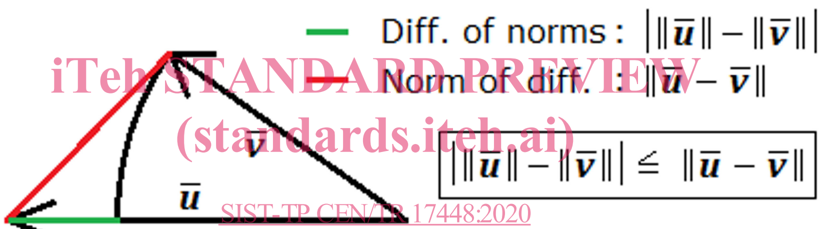

Figure 1 — Triangle Inequality

The question remains as to whether all of them (an in particular those of 3D and horizontal velocity accuracy) are of relevance. Relevance is hard to assess, and rather subjective. Many of the metrics proposed in EN 16803-1 could be questioned in terms of their relevance (it seems difficult to think of an application which makes use of the East Velocity Protection Level, to give an example). However, they have been included for completeness. Whether or not they should be deleted is a relevant discussion but goes beyond the scope of this study, but we can envisage:

— the 3D Velocity Accuracy metric could be removed;

— the Horizontal Velocity Accuracy metric could be transformed into the Horizontal Speed Accuracy metric (then moved to the “Speed” section of the table, in which now it would make sense to make a distinction between 3D and Horizontal), where the horizontal speed is to be understood as the norm of the horizontal projection of the velocity vector.

5.1.3 Integrity Metrics

5.1.3.1 General

Similar issues have been detected as with accuracy metrics. Namely:

— 3D/Horizontal Protection Levels have not been explicitly defined (neither for position nor for velocity). However, if 3D and horizontal errors are properly defined as norms of the corresponding vectors (following the recommendations made in 5.1.1), then expressions such as 3D and Horizontal Protection Levels can be assumed to be self-explanatory without the need of explicit definitions;

— 3D/Horizontal Integrity Risk definitions contain references to such things as 3D/Horizontal position (or velocity) errors, which are undefined. This would be solved by implementing the recommendations stated in 5.1.1;

— along track, cross track, etc. are undefined. This would be solved by implementing the recommendations stated in 5.1.1;

— there is a 3D Velocity Protection Level metric, but there is no Speed Protection Level Metric, which is probably more interesting. In this regard it is proposed to turn 3D and Horizontal Velocity Protection Level metrics into 3D and Horizontal Speed Protection Level metrics, and then move them to a new “Speed” section within the table (much in the same way as in the Accuracy Metrics table).

5.1.3.2 Percentile Computation Procedure

It is stated in EN 16803-1:2016, A.2.1 that Accuracy metrics shall not take into account those epochs in which the output of interest (e.g. horizontal position) is not provided by the GBPT. However, in EN 16803-1:2016, A.2.2.2 it is said that Protection Level performance metrics shall include those epochs in which there is no protection level, which shall be understood as if the protection level was infinite. These two approaches are exactly opposite and it seems contradictory to adopt one of them for accuracy and the other one for protection levels. We briefly discus here both approaches using an example and show a few of their advantages and drawbacks. The example addresses the case of protection level percentile computation, but the same ideas apply to error percentiles (and hence to Accuracy metrics).

Suppose that 10 % of the time there is no position output or no associated protection level and that the CDF of the protection levels is computed taking into account all epochs. Then the maximum value of the protection level, which would normally correspond to the 100th percentile, will rather correspond to the 90th percentile (smaller or equal protection levels than the maximum have been obtained only 90 % of the time, since there is another 10 % without protection levels). Actually, this way of reasoning shows that the whole CDF plot shrinks by a factor 0,9 (with respect to the one computed using only epochs with a protection level) along the ordinate axis. This is illustrated in Figure 2. As a result, all percentiles up to the 90th yield higher values. In particular, the 95th percentile is undefined.

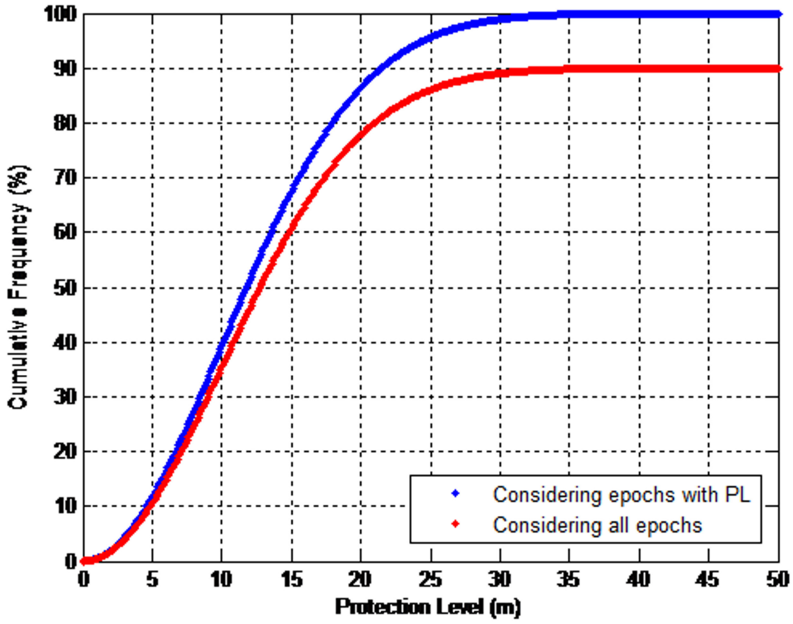

Figure 2 — CDF considering all epochs or only those with Protection Levels

Each approach presents different advantages and drawbacks. If all epochs are considered, the CDF can be used to assess the Protection Level size and Protection Level Availability in a single plot (note that Protection Level Availability metrics have not been defined in EN 16803-1:2016, see 5.2.1). Likewise, in the case of error percentiles, Accuracy and Availability could be assessed in one single plot, which may be seen as an advantage. As a drawback, both metrics (accuracy and availability) get coupled, complicating validation, certification and comparison of different solutions. Besides, some of the percentiles defining the accuracy metric (such as the 95^{th} in the preceding example) may be not computable. Benefits of both approaches are summarized in Table 1.

Table 1 — Benefits of both percentile computation approaches

Metrics	Use all epochs	Only epochs with a valid output
Protection Level Performance	PL size and availability are assessed in a single plot. PL availability can be assessed without the need of additional availability metrics.	PL size and availability are decoupled. All PL size percentiles are well-defined.
Accuracy	Accuracy and availability are assessed in a single plot. Availability can be assessed without the need of additional availability metrics.	Accuracy and availability are decoupled. All error percentiles are well-defined.

Regardless of the final decision, it is recommended to emphasize in the document the approach to be taken in each case, perhaps in a more prominent place than the Annex A (where such explanations are currently placed), in order to avoid misunderstandings. This is especially encouraged if it is decided to keep using different approaches for Accuracy and Integrity metrics.

As to the question how a "valid" output is to be understood (in order to filter out epochs without a valid output when that is the selected approach), the proposed answer is to consider an output valid when no flag indicates otherwise. For instance, assuming that the NMEA standard is used to output the data, any value of the "fix quality" flag in a GGA sentence other than 0 would indicate a valid position.

5.1.3.3 Integrity Risk Computation Procedure

Similar to what has been pointed out previously, a minor concern can be raised about Integrity Risk metrics, which refer to probabilities whose computation procedure has not been clearly specified. For the sake of clarity let us focus on position (rather than velocity) Integrity Risk metrics, although all what is said here can be applied to any of the Integrity Risk metrics. As previously, we are faced with the decision whether to consider all epochs or those with a valid position and an associated Protection Level. When no position and no PL exist, that could be counted as a "safe" epoch (one with no integrity event taking place). The same could be said of an epoch with a position and without a PL. Therefore, those epochs could either be discarded or considered in the IR computation as safe epochs. If they are discarded, the results will be slightly worse (by a factor 1/0,9 approximately 1,1 taking the example of 5.1.3.2) than if they are taken into consideration. However, the impact in the case of the Integrity Risk is somewhat smaller, as a 1,1 factor (taking again the example of 5.1.3.2) applied to an IR figure which is already very small (e.g. 1^{E}-6) does not make much of a difference, especially considering that such small figures can hardly be measured to a high degree of accuracy. Nonetheless, it is recommended to specify whether or not epochs with a valid position and PL are to be considered in the computation of the Integrity Risk.

Although either approach can be acceptable, we are inclined in this case to consider only epochs with valid outputs, which is a slightly more conservative approach than the other one (as it yields slightly worse integrity risk figures).

5.1.4 Availability Metrics

Two availability metrics have been defined in EN 16803-1, both identical except that one refers to position and the other one to velocity/speed. In both cases Availability is defined in terms of the existence of the output of interest (either position or velocity/speed) but nothing is said as to the criteria that an output shall meet to be acceptable and thus be taken into account when computing Availability figures. Since no criteria are specified, it can be interpreted as if all outputs are acceptable, which would allow for unwanted situations such us a GNSS-standalone GBPT which keeps outputting (at its nominal rate) the last known position after a complete loss of GNSS signal (e.g. inside a tunnel) and those outputs being added to the availability count.

In order to avoid this kind of situations it is proposed to reword these metrics specifying that only valid outputs are to be taken into account. For example, Position Availability could be reworded as follows:

Position Availability (T) is the percentage of operating time intervals of length T during which the positioning terminal provides at least one valid position output

Note that This wording differs from the original one only in the appearance of the word “valid”. This should be accompanied by an explanation somewhere along the document as to what is meant by a “valid” output. In line with what was said at the end of 5.1.3.2, this could be understood as an output that is accompanied by a flag (similar to the “fix quality” flag that can be found in the GGA sentence of the NMEA protocol) indicating that the output is healthy (or not indicating otherwise). Similar criteria could be followed in the case of velocity and/or speed.

In order to make things simple, it could be established that one single flag be used to indicate the health status of all provided outputs (position, velocity, speed or protection levels if they are also provided) and that a value of such flag indicating good health shall be understood as all outputs being okay. Otherwise, maybe the existing standard protocols (such as NMEA) would have to be modified to include health status flags for the different outputs (not only for the position). However, for terminals which provide protection levels the NMEA protocol may already be insufficient, so maybe the protocol needs to some evolution anyway.

It may also be worth specifying how the time intervals of length *T* are to be handled when computing Availability (*T*) figures, namely whether or not such time intervals shall be contiguous or they can overlap, and if they can, what is the allowed overlapping. If the above definition is taken strictly, each possible time interval of length T should be considered, which implies a sliding T-window whose offset takes values in a continuum (rather than a discrete set of possible displacements). The computation of the Availability (*T*) figure would therefore imply some integral calculus, not difficult conceptually but rather cumbersome. However, when T is small compared to the time length of the data set at hand (a desirable situation for the sake of statistical significance), the Availability (*T*) figure will show low sensitivity to allowed overlapping, yielding similar values in all cases, from the continuous case to the contiguous one (the latter obviously being computationally much simpler than the former). Whatever approach is taken, it is important that everybody takes the same, and hence it should be specified in the standard. For the reasons just explained it is proposed to use contiguous T-windows for Availability (*T*) computation, and to specify that the first *T* interval shall start at the first epoch of the data set under consideration.

5.1.5 Timing Metrics

5.1.5.1 General

It has been pointed out that the Timestamp Resolution metric might not really be a metric, but rather a feature of the GBPT. It is, certainly, a GBPT feature, and can be easily observed by a simple inspection of the GBPT output. The reason to include it in the list of performance metrics seems to be the fact that it may have an impact on performance.

For instance, when a GBPT combines GNSS with an IMU (or any sensors which delivers data at a high rate, such as car odometers), the synchronisation of the data coming from the different sensors is usually a delicate matter. Matching the GNSS fix (or set of raw measurements) with the right piece of data from the sensor's stream is critical for a smooth and accurate functioning of the navigation system. A poor timestamp resolution of the GNSS output may therefore degrade navigation performance.

The above example addresses the importance of the GNSS timestamp resolution, but it can be argued that the metric does not refer to the GNSS timestamp but to the overall timestamp delivered by the GBPT after obtaining its navigation solution (which in the above example would be a GNSS/IMU hybrid solution). The fact that the GBPT timestamp has poor resolution does not imply that the GNSS timestamp used internally by the GBPT to combine the GNSS and IMU data are also coarse. However, the application layer that used the GBPT position as input may also require high resolution and/or accuracy of the timestamp (e.g. suppose it is to be used by a collision avoidance system).

It shall be noted that, following this line of reasoning, other features of the receiver may need to be included as metrics, including:

— position output resolution (e.g. 1 m could be enough for road tolling but insufficient for autonomous driving);

— velocity/speed output resolution;

— protection level resolution;

— output latency (e.g. a road tolling application may wait for a long time to get the GBPT output, but a safety-critical one may not);

— output rate (e.g. autonomous driving may require higher output rate than road tolling).

On the other hand, Output Latency and Output Rate stability have been said to be not relevant. Again, deciding about the relevance of a metric is no easy task. There is no technical specification known to the authors of this document in which these parameters are specifically addressed, but it could very well be the case that such specifications exist within the automotive industry, especially for systems involving data exchange through the CAN bus. Unfortunately, CAN communications are far from standard, and specifications are kept secret by manufacturers. However, output rate and latency stability may be important when several sensors shall be synchronised (e.g. in hybrid navigation systems). Sensor outputs are subject to delays which are usually calibrated. When these delays are not stable over time, synchronisation issues can occur which have a direct impact on performance. Therefore, it is not clear to the authors that these metrics should be removed. However, if could be proposed to take them out until their relevance can be confirmed (e.g. through consultation to manufacturers).

It has also been pointed out that timestamp accuracy, which was not included as a metric in EN 16803-1 may be relevant. One GP-START partner has reported problems processing PVT data obtained with a COTS mass-market receiver which delivered wrongly timestamped PVT data. However, it is agreed not to include timestamp accuracy as a metric based on:

— timestamp inaccuracy will manifest itself as navigation inaccuracy as long as the vehicle moves;

— it is agreed that inaccurate or corrupted timestamping may lead to hybridization problems as far as other sensors are concerned, but this will result on poor navigation accuracy of the hybridized system;

— if timestamping errors do not result in navigation errors (e.g. in a stationary receiver), then they are not relevant for ITS;

— along the lines of previous point, timing applications, which may require accurate timestamping, are not considered among ITS applications.

This decision could be revised if evidence is shown as to the common need of accurate timestamping at ITS application level as a separate requirement, independent from positioning performance.