Standardization of performances of GNSS-based positioning terminals for ITS applications at CEN/CENELEC/TC5

François Peyret
Head of the Geopositioning laboratory, Institut Français des Sciences et Technologies du Transport, de l'Aménagement et des Réseaux (Ifsttar)
Route de Bouaye – 44344 – Bouguenais – France
+33 2 40 84 59 40, +33 2 40 84 59 98, francois.peyret@ifsttar.fr

ABSTRACT

The paper is about independent performance standards for GNSS-based positioning terminals used in road transport applications. It deals with the activities that have started in 2013 at CEN/CENELEC/TC5 standardization body. A new WG has been created to work on performance definition and assessment of GNSS-based terminals used in road transport applications. The paper will introduce this work and the SaPPART network that has been established in parallel to support the standardization activities on this topic in Europe.

Keywords: standardization, GNSS, ITS, performance, integrity, road transport applications, key performance indicators

INTRODUCTION

This paper will address the issue of performance standardization of GNSS-based positioning terminals for ITS applications carried out at CEN/CENELEC. The first section will introduce the context of the situation and will explain the urgency of the standardization. The second section will draw a state-of-the-art on related R&D topics and standardization activities going on in Europe. The third section will be the main one and will introduce the scope and the philosophy which are driving the work started at CEN/CLC/TC5, whose origin comes from the French BNAE. The fourth section will present the work program and the deliverables foreseen by the group. The fifth and last section will introduce the network of experts and stakeholders SaPPART that has been established in parallel of the standardization activities to support them by unlocking the main underlying scientific issues and by promoting good practice of GNSS in the ITS and personal mobility domains.

1. CONTEXT

Global Navigation Satellite Systems (GNSS) have a very high potential in the development of Intelligent Transport Systems (ITS), Personal Mobility and associated services. This has been widely demonstrated through the use of GPS in supporting the provision of ITS services such

as personal navigation, fleet management, cooperative traffic monitoring and more recently: Road User Charging (RUC), Pay-As-You-Drive insurance, emergency call (eCall), tracking and tracing of dangerous good, Advanced Driver Assistance Systems (ADAS), etc. [1]
Given the principle of GNSS positioning, performance is highly influenced by the conditions of the operational environment. Therefore, GNSS integrators and users are facing two major challenges: the difficult problem of estimating the expected performance of the service when using GNSS, and the lack of standards and certification references on positioning performance, that are necessary to guide their choices [2]. *Integrity* (trust the user can have in the accuracy of the position, i.e. the ability of a system to provide timely and valid warnings to the user when the system must not be used for the intended operation) is a crucial component of this performance, especially for liability-critical and safety-critical applications. These issues are even more pronounced for the ITS services bound to be deployed in urban areas or in freight terminals, where signal propagation degradation can be huge and often have unpredictable effects on GNSS performances.

2. STATE-OF-THE-ART IN EUROPE

2.1 Research and Development

For the last 5 years, a number of collaborative R&D projects, mostly funded by EC via the European GNSS Agency (GSA), have been, or are being, carried out on topics related to the definition, improvement or standardization of the GNSS performance: RCI, GINA, GSC, SIGNATURE, EGNOS-On-The-Road, GNSSmeter, IGNSSRX, TACOT... Most of these projects have pinpointed the fact that EGNOS wasn't as satisfactory for road transport as it is for air transport and that complementary means of improvement had to be studied and developed, like hybridization, cellular assistance, map-aiding, etc., to improve the present GNSS positioning service for a larger deployment of GNSS-based ITS in urban environments.

2.3 Standardization Bodies

From the GNSS side, work is going on mainly in 3 groups: at ETSI Technical Committee on Satellite Communication and Navigation / Satellite Earth Stations and Systems, (SCN/SES): on architecture, data exchanges, performances and tests [3]; at BNAE/CB 5/SGT APP 001 and at CEN/CENELEC/TC5/WG1, on performances and tests, for road applications only.
CEN/CENELEC and ETSI are both mandated by the EC to address this topic [4]. A coordination group is managing the potential overlaps between the 2 bodies.
From the ITS side, some WGs of CEN/TC278, in particular WG1 on EFC are addressing performances of systems using GNSS, but none of them is addressing directly the performance of the GNSS-based terminal itself.

2.2 Support To Standardization

Some specific projects have also been launched to support standardization and certification in Europe: SUGAST, SAGITER, QualiSaR, ITT ENTR/158/PP/ENT/SAT/12/6411.
SUGAST and SAGITER projects have been designed to support the standardization activities carried out at ETSI SCN/SES. QualiSAR [5] is focused on qualification process and facilities. The last project deals only with certification process.

3. METHODOLOGY FOUNDING THE CEN/CENELEC/TC5 WORKS

3.1. Systemic Definition of a Positioning-based Road Transport Service

According to our viewpoint, a *System* providing a *Positioning-based service* consists of a *Positioning terminal* and of an *Application algorithm*, using localization data (terminal outputs) to provide a *Service* for the user (navigation aid, tracking, passage or presence detection, etc.). Figure 1 below illustrates the architecture of such a system.
The terminal itself consists of a series of sensors and an algorithmic layer supplying the application layer with optimal localization data. Sometimes we can talk of *Positioning system*, which can be different from *Positioning terminal* when the localization calculation uses also data sent by a telecommunication system, which can be assistance data (Assisted GNSS), differential GNSS data or SBAS satellite augmentation systems.
The terminal ouputs are generally associated with quality indicators providing information on the uncertainty that can be expected on the output, like estimated standard deviations.

The application algorithm is used to provide the user (in the wide sense, the user can be an automatic system) with useful data (*Application quantities*) based on positioning data.
Depending on the applications, these *Application quantities* can be a position map-matched on a road segment, toll barrier detection or zone entry/exit detection, a speed, a distance, etc.
The *Application quantity* will be generally constructed from position, speed and time data, calculated by the positioning algorithm. In some cases, however, it is better to calculate it from raw data (pseudo-ranges, Dopplers).
The application quantities must be accompanied by data on their quality based on the quality indicators attached to the localization outputs. These quality indicators can be an uncertainty on the quantity or, depending on the application, more advanced indicators: *Protection levels (PL)*, *Probability of false detection* (*PFD*), *Probability of non-detection* (*PND*), etc.

Generally, performance requirements of transport services are defined by end-to-end *Key Performance Indicators* (KPIs). These KPIs need to be shared between performance of *GNSS-based positioning terminal* on the one hand and performance of application-specific algorithms (geofencing, map-matching, filtering…) on the other hand.
In this respect, a generic methodology to handle both performances has to be established.

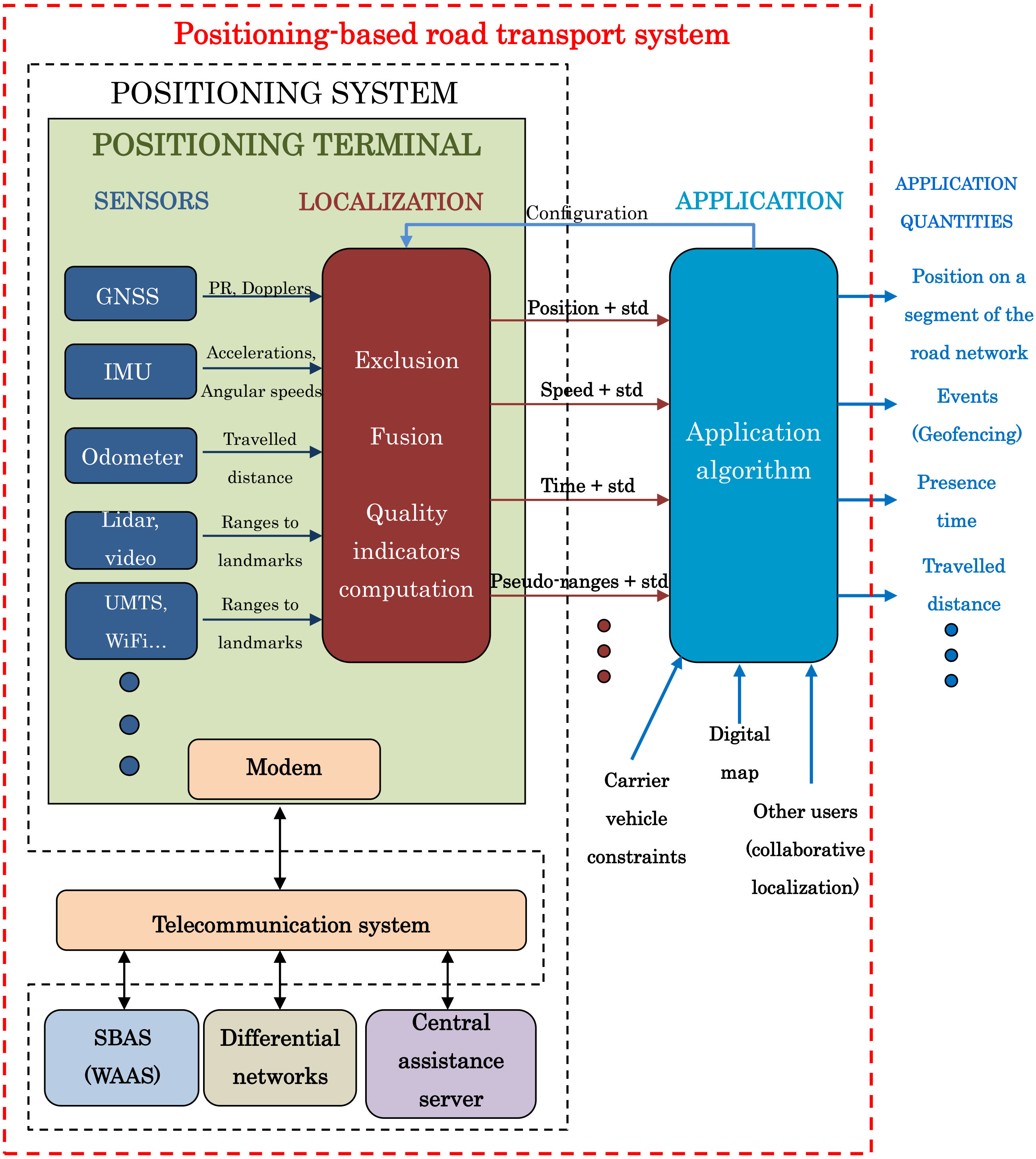

Figure 1. Systemic description of a *Positioning-based road transport service*

3.2. System Engineering Approach

To handle all the aspects of the issue, it is necessary to use a system engineering approach and to propose models for the items that can be modeled.

The overall objective being either to check the compatibility between a terminal and the expected KPIs of an application or to be able to choose (or design) the terminal compatible with the expected KPIs, there is work to be done at the level of the whole system and at the level of the terminal itself.

- At the level of the whole system, tests can be done either on the field, at full scale, or in the lab, by simulation or replay of real data. Our position is that both are necessary: the field tests are necessary to validate the whole chain and to calibrate the simulation models and the simulation tests are necessary to be able to run a high number of tests in order to assess the performances expressed under the form of a very low probability. For instance, a false detection rate of 10^{-6} with a confidence level of 95% for a GNSS-based road rolling system needs at least 3.10^{6} successful tests to be assessed. This is absolutely not feasible at full scale. To carry out a high number of tests in the lab, one needs to be able to simulate the behavior of the terminal in the context in which the performance is expressed.
- At the level of the terminal, the same choice between field tests and simulation/replay tests exists and the answer is the same: tests in lab with constellation simulators or players are of high interest because of their repeatability and their convenience, but field tests are mandatory to calibrate the environments programmed into the simulator, to record data and to assess performances of hybridized terminals needing a movement of the carrier vehicle to function.

3.3. Performance Features and Performance Metrics of a Positioning Terminal

To be able to link the tests at the whole system level and tests at the terminal level, we need first to define how the performance of the terminal can be expressed (*Features*) and how it can be measured (*Metrics*).

In the road application domain, as in many others, the main performance features that come into mind are: *Availability* and *Accuracy*. But, since standards are mainly expected for safety-critical or liability-critical applications, *Integrity* has also to be considered, as well as robustness to security attacks like jamming or spoofing. At CEN, we decided to proceed in two distinct phases: phase 1 would be dedicated to the “classical” features *Availability*, *Accuracy* and *Integrity*, phase 2 to the *Robustness to security attacks* features.

A very important point to stress here is that performance metrics of GNSS-based terminals must be expressed in terms of probabilities since they are highly dependent of the time and the location of the measurement. The conditions in which the measurement sample is acquired are of the highest importance, since they have a great influence on the final performance. We call them *Operational scenario*, the 2 components of it being *Trajectory* and *Environment*.

We propose to consider the following features and metrics.

Accuracy (of position)

Accuracy is one of the most accessible features from the viewpoint of user experience. It can be measured by the error between the position provided by the *Positioning terminal*, when this position is available, and the user's “true” position, generally estimated by a reference measurement system. This error, which is a random variable, is fully characterized by its *Cumulative Distribution Function* (*CDF*), which greatly depends on the environment. The *Accuracy* is generally analyzed in 2D, rarely in 3D for terrestrial applications. In 2D, the error is called *HPE* for *Horizontal Position Error*.

Example of relevant metric for *HPE*: 50% percentile and 95% percentile. More points can be considered if we want to represent more precisely the *CDF*. Figure 2 presents an example of such a *CDF* approximated in this case by the 50% and 95% percentiles: (3 m, 16 m).

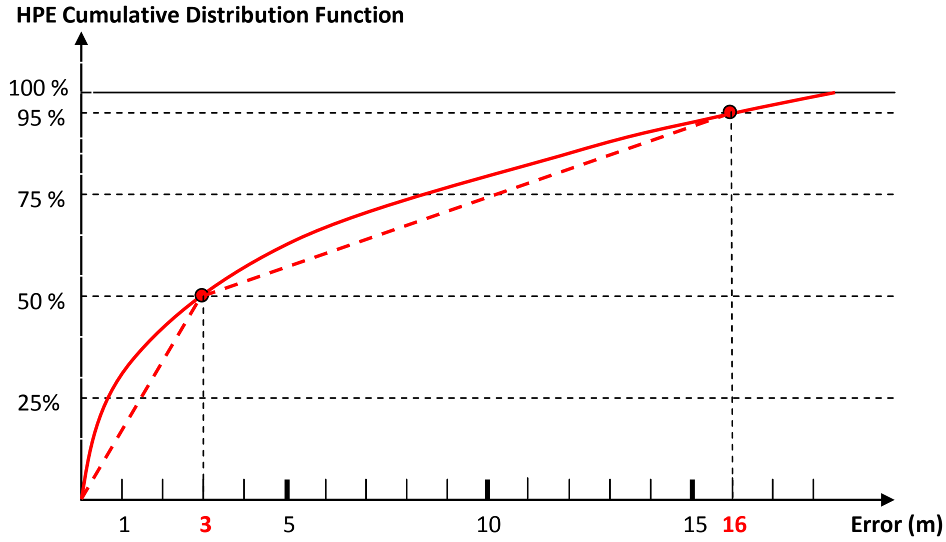

Figure 2. Example of a metric for the *Horizontal Position Error*

Availability (of position)

According to the definitions coming from the civil aviation domain, a positioning system's *Availability* is: "The percentage of time during which the system can be used for the required function in a given zone". "Can be used" means here "is operational with the specified *Accuracy* and *Integrity*". Since the context of road transport is quite different from the one of air transport (specified *Accuracy* and *Integrity* are very rare), we suggest to simplify this definition and to define *Availability* as: "The percentage of time during which the positioning terminal is capable to output a PVT". Another definition might be necessary for the terminals delivering also integrity outputs such as *Protection levels* (see below the definition).

Example of relevant metric: Nb of epochs with a position output / Total Nb of epochs for a given *Operational scenario*.

Integrity (of position)

Integrity is a measurement of the confidence the user can have in the position supplied by the system. For civil aviation again, it is expressed in the form of a probability (or risk) of failure over the period during which the positioning service is provided. More precisely:

- if an *Alarm limit* (maximum allowable level for the position error) has been defined, the *Integrity risk* is the probability that the actual position error exceeds the *Alarm limit* without the user being informed of this before a given time called *Alert time*,
- if no *Alarm limit* has been defined (the case for most of road transport applications), it is the probability that the actual position error exceeds the *Protection level*, which is a parameter computed by the *Positioning system* supposed to over bind the actual error.

In conclusion, for our purpose, we propose to consider 2 distinct integrity features: the 2D

Horizontal Protection Level (*HPL*), which is also a random variable similar to the *HPE* and the *Integrity risk* (*IR*) associated with this *HPL*.
<u>Example of relevant metric for *HPL*</u>: 50% percentile and 95% percentile of the *HPL CDF*.
<u>Example of relevant metric for *Integrity Risk*</u>: percentage of *Misleading Information* (*MI*).

3.4. Performance Classes

Once the features and the metrics are defined, the next challenge is to define the *Performance classes* with respect to the *Performance metric*. For a question of simplicity, we propose to choose a low number of classes for each feature, and only 3 when it is possible.

- For the feature ***Horizontal accuracy***, these 3 classes could be defined by 2 given values of the proposed metric, for instance (2 m, 8 m) and (5 m, 20 m). These 2 values delimitates 3 intervals on each line corresponding respectively to the probabilities 50% and 95% (in cyan, orange and pink on Figure 3 below) and the classification could be done that way:

- when the observed CDF curve of the receiver in test crosses both first intervals (in cyan) it is classified in Class 1, like the purple curve on Figure 3,
- when the CDF curve crosses both second intervals, it is Class2, like the green curve on Figure 3,
- when the CDF curve crosses both third intervals, it is Class 3,
- when the CDF curve crosses a first interval and a second one, it is classified in the lowest one, i.e. in Class 2, idem for 2 and 3.

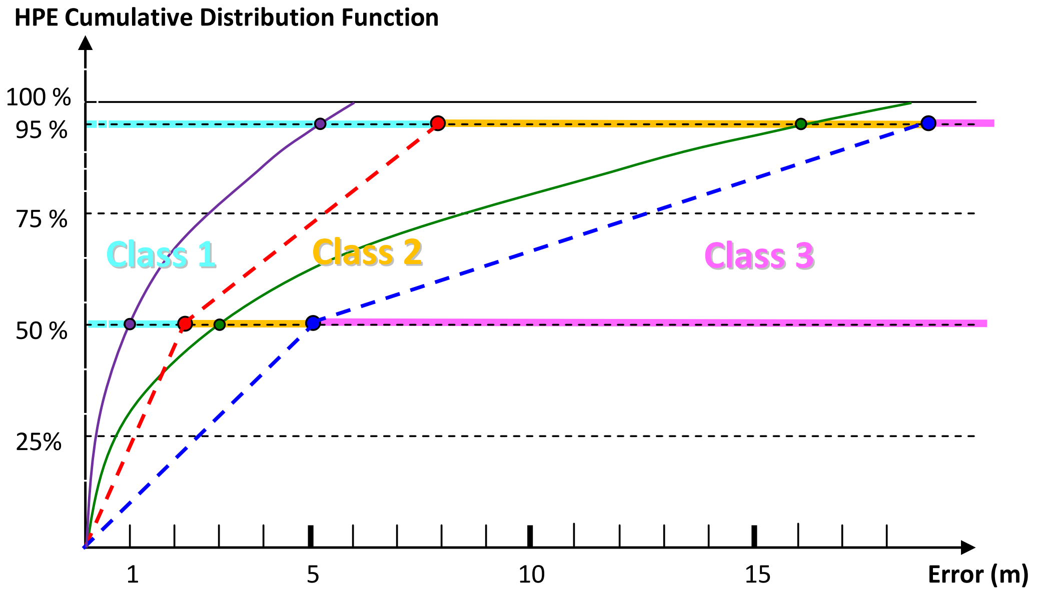

Figure 3. Example of classes definition for the feature *Horizontal Accuracy*

- For the feature ***Availability***, the classification is trivial, since it can be delimited by 2 values of the metric, for instance 50% and 90%.

- For the feature ***Integrity***, which is in fact a double one, composed of *HPL* and *IR*, the issue is a little bit more complex since these 2 dimensions are generally contradictory. As a matter of fact, a very protective *HPL*, with high values, will lead to a null or very low *IR*, but will not be usable in practice (what is the value of an information telling you that your error should be lower than 500 m ?). On the other hand, a low *HPL*, not too far from the *HPE*, will be usable, but the *Integrity risk* might be too high. This trade-off is clearly understandable on the so-called “Stanford plot”, where the measurements for all the epochs are represented on a plot with the true error (*HPE*) in abscissa and the estimated *HPL* in ordinate. On this plot, the bisecting line x = y (in green on Figure 4) delimitates the “safe” region from the ”unsafe one”, but, to be “very safe”, it’s better to be above the line *HPL* = 1.33 *HPE* (red line on the figure).

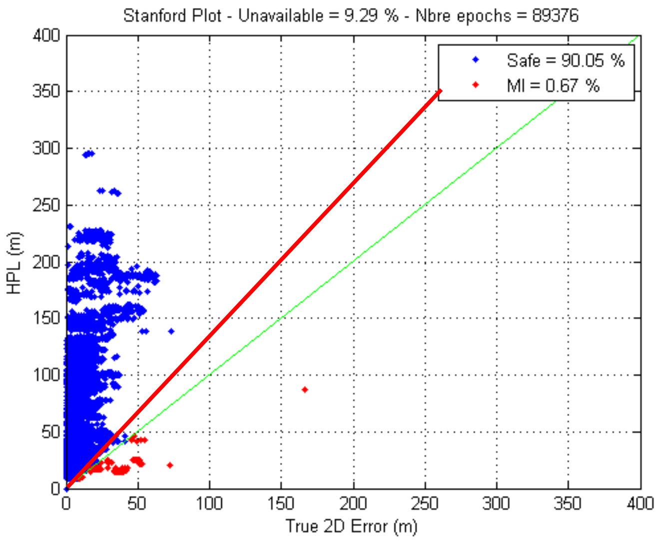

Figure 4. Example of a “Stanford plot” for *Horizontal Integrity*

So, the first dimension of the *Integrity* metric should be the probability to be below the “very safe” line, which will be the definition of the *Integrity Risk* (IR). One can propose 3 classes for instance: *IR* < 0.001%, *IR* < 0.01% and *IR* < 0.1%.

The second dimension is the absolute level of the HPL that could be characterized the same way as we proposed for HPE, i.e. by the location of the 50% and 95% percentiles of the CDF curve of HPL.

This way we could have 9 *Integrity* classes by combining these 2 dimensions of the feature.

3.4. PVT Error Models

Once the *Performance features*, *metrics* and *classes* are defined, it is of high interest to be able to have *PVT error models* corresponding to the classes previously defined.

What we call *PVT Error models* is a mathematical pseudo-random function of time that models the errors of a *Positioning terminal*.

For 2D ***Accuracy***, these models will apply to the X and Y coordinates and should be expressed by: ErMX (t) and ErMY (t). Since there are 3 accuracy classes, there should be 3 corresponding *Error models*.

For 2D ***Integrity***, it is again a little bit more complex since the Error models should apply to the *HPL* an *IR* computation. This point will surely need more investigations.

The *PVT Error models* are necessary for evaluation of end-to-end application performance assuming a given *Positioning terminal* and a given *Application module*, in the case when a performance defined by a very low probability needs simulation tests to be validated.
In this case, assuming we want to evaluate the end-to-end application performance when a *Terminal* of *Class 2* is used, in the context of a given *Operational scenario*, the different steps of the evaluation method are the following (Figure 5):

1. to develop the *Metric* necessary to measure this end-to-end performance from the outputs of the *Road application* algorithm,
2. to choose among the different predefined scenarios the one corresponding to the given context,
3. to create a generic "degraded" trajectory of *Class 2* from the "true" trajectory of the scenario,
4. this "degraded" trajectory being a random signal, to simulate as many times as necessary the running of the application with different "degraded" trajectories and to assess the end-to-end performance.

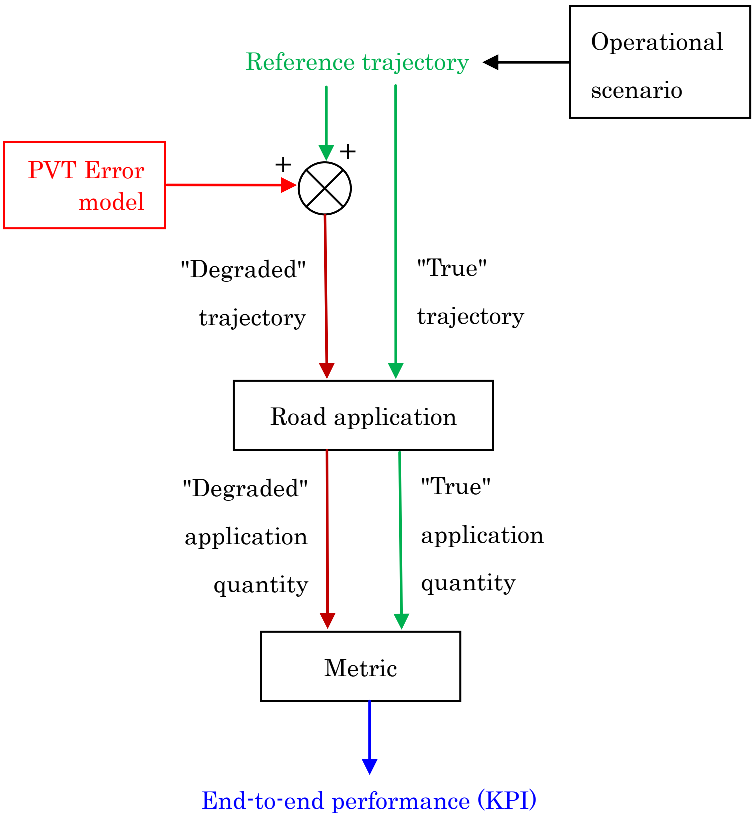

Figure 5. Process of evaluating the end-to-end performance using *PVT Error models*

4. WORK PROGRAM

The work plan of the WG is divided into 3 phases, each one ending with the writing of a

European Norm (EN). Below are described the tasks which are foreseen today.

- The first phase will be the basis for the whole work. It will be devoted to *System engineering guidelines* to manage performances of *Road transport applications* based on GNSS, from end-to-end performance assessment to *Positioning terminal* certification. The resulting document will comprise also a glossary, a classification of the targeted applications and the definition of the basic concepts such as: *Performance features*, *metrics* and *classes*, *PVT Error models*, *Operational scenario*, etc.
- The second phase will be devoted to the definition of performance assessment tests on the *Positioning terminal*, with a particular attention on the field tests to classify the terminal performance in terms of *Accuracy*, *Availability* and *Integrity*.
- The third phase will be devoted to the performance assessment field tests related to the mitigation capacities against interferences and security attacks (jamming and spoofing).

5. THE SAPPART NETWORK

In parallel to the standardization activities, and in particular to bring scientific support to them, a network of European researchers and stakeholders, in the GNSS and/or ITS fields, has been proposed as COST Action (see: http://www.cost.eu/domains_actions/tud/Actions/TU1302) The proposal has been accepted and will enter into action at fall 2013.

The overall aims of this Action are threefold:

1. To develop a framework for the definition of service levels for the GNSS-based positioning terminals, used in ITS and Personal Mobility applications, and the associated examination framework for certification purposes.
2. To promote high-level educational and training programs in the fields of GNSS, GNSS-based ITS and Personal Mobility applications.
3. To promote the use of GNSS in general in ITS and Personal Mobility domains, for their common long-term development and deployment in Europe.

6. REFERENCES

[1] http://www.gsa.europa.eu/go/GSA-releases-GNSS-market-report, November 2010

[2] Cosmen-Schortmann, J, Grush, B, Hamilton, C, Azaola-Sáenz, M, Ángel Martínez-Olagüe, M, “The need for standard performance definitions for GNSS road use metering” in *Proceedings of ITS World Congress* (Stockholm, 2009)

[3] Draft ETSI TR 593 v0.0.4 Satellite Earth Stations and Systems (SES); “Global Navigation Satellite System based locations systems; Minimum performance and features” (May 2012)

[4] Final report Phase 2 by CEN/BT/WG 202 about M/415 Programming Mandate addressed to CEN, CENELEC and ETSI to establish Space industry standards (July 2009)

[5] Reinbold, F, Wegener, M, and Schnieder, E, “QualiSaR – Development of a Qualification Procedure for the Usage of Galileo Satellite Receivers for Safety Relevant Applications” in *Proceedings of European Navigation Conference GNSS 2012* (Gdansk, Poland, 2012)