3GPP TSG-RAN WG2 Meeting #113-e***R2-20xxxxx***

Electronic, January XXXXX, 2020

**Agenda item:** 8.XX.X

**Source:** Swift Navigation

**Title:**  [Post112-e][618][POS] – KPIs and Use Cases Text Proposal

**Document for:**  Agreement

# 1. Introduction

This document contains the updated KPIs and Use Cases text proposal (originally submitted as R2-2010877 [1] to RAN2#112-e) based on feedback from the following email discussion [2], which also includes [3][4]:

[Post112-e][618][POS] Finalise integrity text proposals (Swift)

Scope: Refine the text proposals in R2-2010877/R2-2010878/R2-2010879.

Intended outcome: Agreeable TPs

Deadline: Long

The email discussion was undertaken in two phases which are recorded in Appendix A (Phase 2) and Appendix B (Phase 1) below. The appendices will be removed in the final Tdoc submission but are included here for review.

# 2. Moderator Summary

There was unilateral agreement on all proposals in Phase 2. Nokia and InterDigital clarified the comment from OPPO, confirming that GNSS positioning integrity can be used for outdoor IIoT use cases. ESA’s editorial suggestions were also adopted (i.e. by including ‘positioning’ in the headings for 9.1 and 9.1.1 and adding the reference to EGNOS).

# 3. Conclusion

**Proposal 1: Agree to adopt the term feared event in the TP.**

**Proposal 2: Agree to remove the term hazardous from the AL definition but adopt the term for general use in the TP.**

**Proposal 3: Agree to adopt the updated definitions of MI, HMI and Integrity Event in Section 3.1.**

**Proposal 4: Agree to adopt the AGV examples in Table 9.2.4.**

**Proposal 5: Agree to adopt the Rail text in Section 9.2.2.**

**Proposal 6: Agree to adopt the ‘KPIs and Use Cases’ TP as the baseline text for the TR.**

**Are there any remaining questions or comments to be addressed for the KPIs and Use Cases text proposal?**

|  |  |
| --- | --- |
| **Company** | **Comment** |
|  |  |
|  |  |

# 4. Text Proposal

*Start of Text Proposal*

# 2 References

[1] 3GPP TR 22.872: “Study on positioning use cases”.

[2] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[3] RP-202094: "Study on NR Positioning Enhancements".

[4] 3GPP TR 38.855: "Study on NR Positioning (Release 16)".

[5] R2-2006541, TP for Study on Positioning Integrity and Reliability, Swift Navigation, Deutsche Telekom, u-blox, Ericsson, Mitsubishi Electric, Intel Corporation, CATT, UIC.

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[9] GSA-MKD-RD-UREQ-250283, “Report on Road User Needs and Requirements: Outcome of the European GNSS’ User Consultation Platform”, Issue/Rev: 2.0, 2019.

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[11] 5GAA, “White Paper – C-V2X Use Cases Methodology, Examples and Service Level Requirements, 2019.

[12] Global Positioning System Wide Area Augmentation System (WAAS) Performance Standard, Department of Transportation USA, Federal Aviation Authority, Edition 1, October 2008.

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[18] European GNSS Agency, “GNSS User Technology Report issue 3”, 2020.

[19] Air Force Research Laboratory, “IS-AGT-100 Chips Message Robust Authentication (Chimera)”, 2019.

[20] 3GPP TR 22.804, “Study on Communication for Automation in Vertical Domains”.

[21] 3GPP TS 38.305, “Stage 2 functional specification of User Equipment (UE) positioning in NG-RAN”.

[22] 5G ACIA White Paper, "5G for Automation in Industry: Primary use cases, functions and service requirements", July 2019.

[23] Working Group C (WG-C), “EU-U.S. Cooperation on Satellite Navigation”, ARAIM Technical Subgroup, Interim Report, Issue 1, December 2012.

[24] EGNOS Open Service (OS) Service Definition Document, European Commission, Version 2.3, 2017.

[25] Elliott D. Kaplan, Christopher J. Hegarty, “Understanding GPS/GNSS Principles and Applications” Third Edition, Artech House, 2017.

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# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

**Positioning Integrity:** A measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the LCS client when the positioning system does not fulfil the condition for intended operation.

**Integrity Availability:** The integrity availability is the percentage of time that the PL is below the required AL.

**Feared Event:** Feared Events are considered to be all possible events (e.g., of natural, man-made, systemic or operational nature) that can cause the computed position to deviate from the true position, regardless of whether a specific fault can be identified in one of the positioning systems or not.

**Target Integrity Risk (TIR):** The probability that the positioning error exceeds the Alert Limit (AL) without warning the user within the required Time-to-Alert (TTA).

NOTE: The TIR is usually defined as a probability rate per some time unit (e.g., per hour, per second or per independent sample).

**Alert Limit (AL):** The maximum allowable positioning error such that the positioning system is available for the intended application. If the positioning error is beyond the AL, the positioning system should be declared unavailable for the intended application to prevent loss of positioning integrity.

NOTE: When the AL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Alert Limit (HAL) or Vertical Alert Limit (VAL) respectively.

**Time-to-Alert (TTA):** The maximum allowable elapsed time from when the positioning error exceeds the Alert Limit (AL) until the function providing positioning integrity annunciates a corresponding alert.

**Misleading Information (MI):** A MI event occurs when, the positioning system being declared available, the positioning error exceeds the PL.

**Hazardous Misleading Information (HMI):** An HMI event occurs when, the positioning system being declared available, the positioning error exceeds the AL without annunciating an alert within the TTA.

**Integrity Event:** An Integrity Event occurs when the positioning system outputs HMI.

## 3.2 Symbols

## 3.3 Abbreviations

**AL Alert Limit**

**HAL Horizontal Alert Limit**

**HMI Hazardously Misleading Information**

**HPL Horizontal Protection Level**

**MI Misleading Information**

**PE Positioning Error**

**PL Protection Level**

**TIR Target Integrity Risk**

**TTA Time-to-Alert**

**VAL Vertical Alert Limit**

**VPL Vertical Protection Level**

*Next Text proposal*

9 Positioning integrity and reliability

9.1 Integrity Overview – Background Information

### 9.1.1 Integrity Concepts

The ability to navigate safely means users must trust their estimated position with a high degree of confidence. The trustworthiness of position estimates is the study of positioning integrity, which is adapted from TR 22.872 [1] as follows:

**Positioning Integrity:** A measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the LCS client when the positioning system does not fulfil the condition for intended operation.

Positioning integrity monitoring[[1]](#footnote-1) is already supported by GNSS service providers, but there is no standard for expanding the ecosystem of connected devices which can benefit from positioning integrity. This study investigates new integrity assistance data and procedures to be considered in LPP and associated specifications, to assist in quantifying positioning integrity for the positioning system.

#### 9.1.1.1 Accuracy and Integrity

To understand the necessity of introducing the concept of positioning integrity, it is important to understand how it differs from the more familiar concept of Accuracy.

Positioning accuracy and positioning integrity are related but separate concepts, and for many use cases, accuracy alone is insufficient to meet the requirements. Positioning devices and services are typically designed to report the distribution of errors that characterize the overall system performance, which is often specified as an error percentile representing the accuracy. For example, a road vehicle with an embedded UE positioning client may report a lane-level accuracy of <50cm 95th percentile. In this case, the UE is indicating that, based on all the computed positions, its estimated accuracy is better than 50 cm, 95% of the time. For the remaining 5%, the position error is unknown. In fact, these errors might reach 10s or 100s of meters due to multiple different error sources. The 5% of errors are essentially unbounded without any way to reliably validate their distribution. In the case of GNSS, these errors could include constellation geometry (i.e., Dilution of Precision), sharp atmospheric gradients or irregularities, and local receiver effects such as high measurement noise or multipath.

Each time a position is provided, positioning integrity can be used to quantify the trust on the provided position. Positioning integrity is therefore a method of bounding these errors and this can be done to a much higher confidence. For example, a Target Integrity Risk (TIR) of 10-7/hr translates to a 99.99999% probability that no hazardously misleading outputs occurred in a given hour of operation. The TIR sets the target for determining which feared events need to be monitored in order to meet the specified Alert Limit (AL) at this level of probability. A lower TIR introduces a wider range of threats (i.e., feared events) that need to be monitored to improve confidence in the estimated position. Erroneous position estimates which do not meet the positioning integrity criteria can then be omitted in the final positioning solution, allowing only the valid position estimates to be utilized, which also leads to higher accuracy.

#### 9.1.1.2 Integrity Key Performance Indicators (KPIs)

The following KPIs for positioning integrity are defined for the study:

**Target Integrity Risk (TIR):** The probability that the positioning error exceeds the Alert Limit (AL) without warning the user within the required Time-to-Alert (TTA).

NOTE: The TIR is usually defined as a probability rate per some time unit (e.g., per hour, per second or per independent sample).

**Alert Limit (AL):** The maximum allowable positioning error such that the positioning system is available for the intended application. If the positioning error is beyond the AL, the positioning system should be declared unavailable for the intended application to prevent loss of positioning integrity.

NOTE: When the AL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Alert Limit (HAL) or Vertical Alert Limit (VAL), respectively.

**Time-to-Alert (TTA):** The maximum allowable elapsed time from when the positioning error exceeds the Alert Limit (AL) until the function providing positioning integrity annunciates a corresponding alert.

**Integrity Availability:** The integrity availability is the percentage of time that the PL is below the required AL.

The relationship between the KPIs and the Protection Level (PL), and their impacts on the positioning solution are further examined below.

#### 9.1.1.3 Integrity Protection Level (PL)

The Protection Level (PL) is a real-time upper bound on the positioning error at the required degree of confidence, where the degree of confidence is determined by the TIR probability.

The PL is defined as follows:

**Protection Level:** The PL is a statistical upper-bound of the Positioning Error (PE) that ensures that, the probability per unit of time of the true error being greater than the AL and the PL being less than or equal to the AL, for longer than the TTA, is less than the required TIR, i.e., the PL satisfies the following inequality:

**Prob per unit of time [((PE> AL) & (PL<=AL)) for longer than TTA] < required TIR**

NOTE: When the PL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Protection Level (HPL) or Vertical Protection Level (VPL) respectively.

NOTE: A specific equation for the PL is not specified as this is implementation-defined. For the PL to be considered valid, it must simply satisfy the inequality above.

The PL is used to indicate the positioning system availability, as when the PL is greater than the AL, the system is considered unavailable (see Stanford Diagram below). The PL establishes a more rigorous upper bound on the positioning error by taking into consideration the additional feared events which have a lower occurrence (i.e., lower TIR) compared to the nominal events considered in the standard accuracy estimate alone. The lower the TIR, the more feared events that need to be considered.

Fault feared events are those which are intrinsic to the positioning system and typically caused by the malfunction of an element of the positioning system (e.g., constellation or ground network failures). Fault-free feared events occur when the positioning system inputs are erroneous, but the event is not caused by a malfunction of the positioning system. In the GNSS context for example, fault-free feared events include nominal effects experienced every day such as poor satellite geometry, larger atmospheric gradients, and signal interruption, all of which can degrade positioning performance without causing the system to fail. A common limitation of existing industry functional safety standards, as summarized in [5], is that only the fault conditions are considered. In practice, however, the fault-free conditions also have a material contribution to the total integrity risk budget and must therefore be monitored.

The PL is necessary to ensure all potential faults and fault-free events down to the required TIR are considered. It bounds the tails of the distribution with higher certainty (per unit of time) and provides a measure for ensuring only those positions whose positioning integrity has been validated within the TIR are included in the final positioning solution. By contrast, the standard accuracy estimate only considers a subset of feared events up to a nominal percentile (e.g., 2-sigma, 95%), based on the entire distribution of estimated position errors.

#### 9.1.1.4 Relationship between the PL and KPIs

The TIR is a design constraint for a positioning system and represents the probability that a positioning error exceeds the AL, but the positioning system fails to alert the user within the required period of time (i.e., TTA). In practice, the TIR is very small. For example, <10-7/hr TIR translates to one failure permitted every 10 million hours (equivalent to 1142 years approximately).

Positioning integrity system failures are known as Integrity Events and integrity event occurs when the positioning system outputs Hazardous Misleading Information (HMI). HMI occurs when, the positioning being declared available, the actual positioning error exceeds the AL without annunciating an alert within the required TTA. Misleading Information occurs when, the positioning system being declared available, the actual positioning error exceeds the PL. Typically, positioning systems are designed to tolerate some level of MI, provided the system can continue to operate safely within the AL. To properly monitor for integrity in the positioning system, both the fault and fault-free conditions which potentially lead to MI or HMI need to be characterized for the network and the UE.

Figure 9.1.1.4-A illustrates the concept of MI and HMI with respect to the KPIs, PL and PE.

 

**Figure 9.1.1.4-A:** Relationship between Positioning Error (PE), Protection Level (PL), Alert Limit (AL), MI and HMI [6].

A useful representation for interpreting the relationship between the positioning integrity KPIs and PL is the so-called Stanford Diagram [7] in Figure 9.1.1.4-B. It should be noted that the Positioning Error (PE) in this diagram is the difference between the true position and the estimated position, computed by the positioning device. In practice, the true position is not known.



**Figure 9.1.1.4-B:** Stanford Diagram for integrity events, adapted from [7][8].

Important observations can be made from Figure 9.1.1.4-B in the context of this study:

1. The conditions represented above the diagonal line (Nominal Operations, System Unavailable) mean the positioning system is operating as intended by correctly detecting when the system should or should not be available.
2. The conditions represented below the diagonal line mean the system is not operating as intended. These conditions are what the positioning integrity system is designed to protect against, i.e., by monitoring the necessary fault and fault-free events to protect against MI or HMI for a given TIR. This concept is further described:
	* The TIR is equivalent to the probability per unit time of HMI, corresponding to the red block in the Stanford Diagram. The rate of MI (corresponding to the orange region), while undesirable, does not contribute towards the TIR.

In practice, positioning integrity systems are designed to tolerate some level of MI or HMI for a period of time within the TTA, without exceeding the TIR. This framework underpins the PL definition in this study (Section 9.1.1.3) and is particularly important for systems with communication latency, such as 3GPP NR, given assistance data can be monitored and sent by the network (i.e., the basis of this study). Sufficient time is therefore needed to signal that a fault is present. There is nothing prohibiting the TTA being set to zero for instantaneous detection, however a grace period must be accommodated to allow some level of functionality to be offloaded to the network when the network is utilized. Hence, the TTA depends on the overall positioning integrity system design (including 3GPP and non-3GPP elements) and is specified by the positioning system owner (e.g., a vehicle manufacturer) alongside the TIR and AL.

1. Interpretations when the system is **available** (PL<AL):
* **Nominal Operations (PE<PL):** the solution is available and operating safely without an integrity event.
* **Misleading Information (PE>PL & PE<AL):** the solution is available but contains an MI integrity event due to PE>PL. It is still operating safely given PE does not exceed the AL.
* **Hazardous Misleading Information (PE>PL & PE>AL):** the solution is available but contains an HMI integrity event due to PE>AL. It is still declared safe (PL<AL) when it should not have been.
1. Interpretations when the system is **unavailable** (PL>AL):
* **System Unavailable, False Alert (PE<PL & PE<AL):** the solution is unavailable but is a false alert integrity event, given PE<AL.
* **System Unavailable (PE<PL & PE>AL):** the solution is unavailable and operating as intended without an integrity event given PE>AL was properly detected.
* **System Unavailable and Misleading (PE>PL & PE>AL):** the solution is unavailable and contains a MI (PE>PL) integrity event.

## 9.2 Use Cases

RAT-Independent GNSS positioning integrity monitoring has a long operational history in the field of civil aviation [12][13][14][15]. The positioning integrity framework examined in this study extends beyond aviation, to address a broader suite of use case and architectural considerations for the 3GPP system. These concepts are further illustrated by the use case descriptions and KPIs provided below, including a particular focus on safety-critical and liability-critical applications, requiring the capability to validate the estimated position with greater trust.

### 9.2.1 Automotive

#### 9.2.1.1 Road-Level Identification and Road-User Charging

Positioning integrity is a key input to determining whether a road vehicle is traveling on a highway or a neighbouring access road (e.g., a collector-distributor lane). For example, consider a manufacturer wanting to ensure their Advanced Driver-Assistance Systems (ADAS) only activates when the vehicle is on a highway. This requires the UE to determine with a high degree of positioning integrity which road the vehicle is traveling on, in order to avoid the potential for unintended ADAS functionality on the access road (or conversely to ensure the appropriate functionality has been activated on the highway). The road vehicle may also be subject to road-user charging with fees that vary depending which road is used, also requiring positioning integrity validation.

Consider an access road that is within 3 metres of a freeway, with a corresponding AL of 3 metres and TIR of 1 x10-7/hr specified by the vehicle manufacturer. The road vehicle connects to a positioning integrity service provider via the mobile network to request UE-Based positioning integrity assistance data. The assistance data is applied by the UE alongside its local positioning measurements in order to compute the real-time PL. So long as the PL remains below the AL, the positioning system is available and functioning as intended, and the road-level identification can be made safely. If the PL exceeds the AL, the impacted positioning system should be declared unavailable on the vehicle and a road-level determination is not possible. For example, a network-detected fault can be flagged in the positioning integrity assistance data, resulting in a larger PL computed by the UE.

Another important positioning integrity aspect to take into account in road-user charging and other applications (like pay how you drive insurances) is that, because of their intrinsic nature, they have to be robust against attempts to deceive the positioning system. In these types of applications, the driver of the vehicle may be motivated to alter the position of its own vehicle in order to avoid being charged. Hence, the positioning integrity of the vehicle position needs to be ensured by being able to detect these deception attempts, for example by employing anti-tamper equipment and by cross-checking different positioning sources.

#### 9.2.1.2 Lane-Level Identification

The same concepts and methods from 9.2.1.1 also apply to validating the lane in which the vehicle is traveling. Lane change warnings and manoeuvres are a crucial input to enabling various Levels of autonomy [16] which are illustrated in the 5GAA use case requirements [11], such as an AL of 1.5m and TIR of 1x10-7/hr or lower.

The ability to handle faults almost instantaneously on a road vehicle is absolutely critical in order to recover the situation and avoid a potential collision between lanes. The UE is responsible for monitoring localized events which need to be detected in the shortest time possible, i.e., ‘highly dynamic’ feared events (e.g., multipath, cycle slips and satellite feared events in the case of GNSS). The network is therefore used to monitor the low dynamic threats, which are less time-critical but still depend on a reliable communication channel with the UE. In the automotive and other 5G positioning use cases, the TTA is also far more stringent (e.g., 100ms in some cases) compared with an aviation TTA of 6 seconds (or slower) for precision approaches. Hence, the low latency of the 3GPP communications presents a strong synergy for supplying positioning integrity assistance data that is secure and assured.

Once again, the positioning system should remain available unless the PL exceeds the AL, in which case the system should be unavailable and the corresponding ADAS functionality on the vehicle disengaged. To avoid an integrity event, any feared event with an occurrence probability higher than the TIR (i.e., >1x10-7/hr) needs to be detected and mitigated within the TTA[[2]](#footnote-2). The UE application is typically responsible for issuing alerts to inform the preventative or remedial actions required by the positioning system.

If a feared event occurs at the network or UE, the positioning system should be capable of determining its effect on the PL relative to the AL, within the required TTA, such that the position reported by the UE remains fault-free (i.e., even if the fault-free position leads to the system being unavailable). The TTA therefore represents the ability of the system to recover before being impacted by a potential integrity event. For some use cases, the TTA may simply be set to zero depending on the implementation requirements.

### 9.2.2 Rail

 9.2.2.1 Safety-Critical Applications

**Automatic Train Protection** (ATP) applications are used to ensure that trains run safely and efficiently on the right tracks with appropriate speed. Automatic Train Protection aims to prevent a train proceeding beyond the point of danger and to prevent the speed of the train exceeding the permissible limit in the event of a driver error. It consists of the safe determination of position, speed and direction of train movement in order to supervise the safe movement of the train up to its stopping point. This application requires the combination of several functions (or lower level applications) which in turn are strongly dependent of the accurate and safe determination of position and speed of the trains. There are many ATP applications where positioning integrity could be employed, among them one can include Enhanced Odometry, Absolute Positioning, Cold Movement Detection, Train integrity and train length monitoring, Track Identification, Odometer Calibration, and Level Crossing Protection.

**Emergency Management** applications, like the trackside personnel protection (to protect personnel working on or close to the track from the trains using the network) and the door control supervision (to enable the opening of specific doors at particular stations), are also safety-critical applications where positioning integrity will improve the performances and reduce risks.

#### 9.2.2.1 Liability-Critical Applications

**Asset Management**. The accuracy and confidence on the position needed for the location of the assets in some cases can be demanding and requiring high precision and reliable surveying. Fixed asset management applications are linked with the railway environment, from the infrastructure surveying and structural monitoring to the trackside equipment. Rolling stock asset management applications are in charge of the vehicles that move on a railway including both powered and unpowered vehicles, for example locomotives, railroad cars, coaches, and wagons. Rolling stock applications include: fleet management, cargo monitoring, infrastructure charging, energy charging and hazardous cargo monitoring.

**Protection and Emergency Management Systems**. This group includes applications such as trackside personnel protection, management of emergencies and train warning systems. Management of emergencies can be greatly improved if an accurate, reliable and continuous location of the train is available, allowing the emergency teams to optimise their operations. Train warning systems are employed when some railways require a special warning to passengers on a platform when a train is approaching and is expected to pass the platform at a speed greater than a defined level. This application requires reliable details of train location, speed and other infrastructure data, and may result in an automatic station announcement via a public service broadcast.

**Traffic Management and Information Systems**. This group of applications includes traffic management systems (dispatching), but also on-board train monitoring and recording unit, hazardous cargo monitoring and infrastructure charging.

### 9.2.3 Industrial IoT

Editor’s note: Definition of the IIoT use cases is FFS and the examples in this study are limited to those requiring RAT-Independent GNSS positioning.

In contrast to consumer-oriented Internet of Things (IoT), Industrial IoT (IIoT) use cases predominantly focus on operational, safety, and financially beneficial applications of the IoT ecosystem for businesses, infrastructure, and various industries. IIoT positioning integrity/reliability requirements are essential given various safety, payment, and regulatory critical applications. There are many outdoor IIoT devices/UEs employing GNSS-based positioning in various industries that include, but not limited to: Construction, Agriculture/forestry/fishing (smart farming), Oil/Gas industries, and Smart cities (traffic, electric and water systems, waste management, public safety, schools) derived from [1][20]. An illustrative example relating to Automated Guided Vehicles (AGV) is provided below.

#### 9.2.3.1 Path and Zone Identification for AGV

Positioning integrity is a key input to determining whether an AGV such as a forklift, in a factory or an open space such as ports or construction buildings, is traveling on the narrow halls within lots of different machinery, aside from the demanding positioning accuracy, the trust needs to be assigned for the path and the zone of its movements. AGV not running into anything unexpectedly is something that needs to be assured. This requires that the AGV, which is the UE in this use-case, to determine with a high degree of positioning integrity which path it can travel within its defined work task. One can also consider that an industrial scenario can have several different zones in which different levels of positioning integrity can be defined, and hence depending on demand of the works in each zone the positioning methods and positioning integrity KPIs can be defined in respect to those. Once again, the positioning system should remain available unless the PL exceeds the AL, in which case the system should be unavailable and the corresponding AGV functionality on the vehicle is disengaged. The set AL for such use-case depends on how large and how densely equipped the factory is, and hence it is reasonable to assume that it can be set to some value between 0.5m to 3m depending on the controlled area use-case and demands. Further illustration of AGV, which requires support for positioning for tracking, routing and guiding is provided in [22].

### 9.2.4 Use Case Summary

Table 9.2.4 is adapted from [9][10] and supplemented by [8][11]. It summarises the typical KPI ranges to be expected on implementation for the Automotive and Rail categories. Importantly, the KPIs are illustrative only; KPIs are typically specified by the positioning system provider on implementation (e.g., a vehicle OEM), taking into consideration the 3GPP and non-3GPP components of the system.

**Table 9.2.4: KPI examples for the Automotive, Rail and IIoT use cases [8][9][10][11].**

NOTE: KPIs are defined by the service provider implementation.

|  |
| --- |
| **AUTOMOTIVE EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| **Safety-Critical Applications*** Warnings (red light, obstacle, queue, curve speed, blind spot lane change, pedestrians etc)
* Automated Driving (lane-level or better)
* Emergency Brake Assist
* Forward Collision Avoidance
 | Typical range: ≥10-8/hr to ≤10-6/hr | Typical range: ≥1.5m to <5m | Typically ranges from 100s of milliseconds to <10 seconds | Typically ranges from 95% to 99.9% or greater |
| **Payment Critical Applications*** Road User Charging (RUC)
* Pay Per Use Insurance
* Taxi Meter
* Parking Fee Calculation
 | Typical range: ≥10-6/hr to ≤10-4/hr | Typical range: ≥1.5m to <25m | Typically ranges from 95% to 99.9% or greater |
| **Smart Mobility** * Freight and Fleet Management
* Cargo/Asset Management
* Vehicle Access/Clearance
* Emergency Vehicle Priority
* Speed Limit Information
* In-Vehicle Signage
* Reduce Speed Warning
* Dynamic Ride Sharing
 |
| **RAIL EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| **Safety-Critical Applications** * Absolute Positioning
* Train Awakening
* Cold Movement Detector
* Track Identification
* Level Crossing Protection
* Train Integrity and Train Length Monitoring
 | Typical range: ≥10-9/hr to ≤10-8/hr | Typical range: ≥2.5m to <25m | Typically <7s | Typically ranges from 95% to 99.9% or greater |
| **Liability-Critical Applications** * Trackside Personal Protection
* Management of Emergencies
* Train Warning Systems
* Infrastructure Charging
* Hazardous Cargo Monitoring
* On-Board Train Monitoring and Recording Unit
* Traffic Management Systems
 | TBD | Typical range: ≥25m to <62.5m | Typically ranges from seconds to <30s | Typically ranges from 95% to 99.9% or greater |
| **IIOT EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| **AGV Applications** * Mobile device tracking
* Asset tracking
* Process automation
* Inbound logistics
 | Typical range: ≥10-8/hr to ≤10-1/hr | Typical range: ≥0.5m to <30m (vertical/horizontal) | Typically ranges from 100s of milliseconds to <10 seconds | Typically ranges from 95% to 99.9% or greater |

*End of Text proposal*

# References

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<https://www.3gpp.org/ftp/tsg\_ran/WG2\_RL2/TSGR2\_112-e/Inbox/Chairmans\_Notes>.

[3] R2-20xxxxx Email Discussion [618] TP on Integrity Error Sources\_Draft

[4] R2-20xxxxx Email Discussion [618] TP on Integrity Methodologies\_Draft

1. PHASE 2

# 1. PHASE 2 - Introduction

This document is Phase 2 of the following email discussion [1][2][3]:

[Post112-e][618][POS] Finalise integrity text proposals (Swift)

Scope: Refine the text proposals in R2-2010877/R2-2010878/R2-2010879.

Intended outcome: Agreeable TPs

Deadline: Long

It should be reviewed alongside the other email discussion documents:

* Email Guideline - [Post112-e][618][POS] Integrity TPs [3]
* [618] Error Sources – PHASE 2 Draft TP [4]
* [618] Methodologies – PHASE 2 Draft TP [5]

# 2. PHASE 2 – Moderator Summary

A summary of key topics from Phase 1 (Appendix A) is provided below. The summary is grouped based on the common themes raised in Questions 1 to 3 rather than individual summaries for each question.

## 2.1 Feared events

There was unilateral consensus to adopt the term ‘feared event’ based on the majority view. Some companies (Nokia and InterDigital) noted the term is less familiar from a telecommunications point of view but recognize it is standard terminology for positioning integrity.

**Proposal 1: Agree to adopt the term feared event in the TP.**

## 2.2 Hazardous

All comments indicated support for the term hazardous now that the AL definition has been updated. The comments from Vivo and ZTE also indicated they prefer to keep the term hazardous.

**Proposal 2: Agree to remove the term hazardous from the AL definition but adopt the term for general use in the TP.**

## 2.3 Definitions

Swift Navigation proposed to add the definitions for Fault, Fault-free, MI, HMI and Integrity Event. ZTE agreed that MI, HMI and Integrity Event should be added. U-blox proposed updates to the definitions of MI and Integrity Event, which were adopted below (the corresponding text in 9.1.1.4 was also updated).

**Proposal 3: Agree to adopt the updated definitions of MI, HMI and Integrity Event in Section 3.1:**

* **Misleading Information (MI):** A MI event occurs when, the positioning system being declared available, the positioning error exceeds the PL.
* **Hazardous Misleading Information (HMI):** A HMI event occurs when, the positioning system being declared available, the positioning error exceeds the AL without annunciating an alert within the TTA.
* **Integrity Event:** An Integrity Event occurs when the positioning system outputs HMI.

## 2.4 IIoT Examples

Nokia proposed to include examples of AGV applications and KPI ranges in Table 9.2.4 which was supported by ESA. InterDigital and u-blox also agreed but proposed some updated naming and values to be more general.

**Proposal 4: Agree to adopt the AGV examples in Table 9.2.4.**

|  |
| --- |
| **IIOT EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| **AGV Applications** * Mobile device tracking
* Asset tracking
* Process automation
* Inbound logistics
 | Typical range: ≥10-8/hr to ≤10-1/hr | Typical range: ≥0.5m to <30m (vertical/horizontal) | Typically ranges from 100s of milliseconds to <10 seconds | Typically ranges from 95% to 99.9% or greater |

## 2.5 Rail Text

ESA proposed additional text descriptions for the Rail use case to accompany the examples in Table 9.2.4.

**Proposal 5: Agree to adopt the Rail text in Section 9.2.2.**

## 2.6 General

ESA indicated certain text could be removed to make the TP more concise and these proposals have been adopted in the updated TP below, as indicated in track changes.

## 2.7 Summary of Proposals

**Proposal 1: Agree to adopt the term feared event in the TP.**

**Proposal 2: Agree to remove the term hazardous from the AL definition but adopt the term for general use in the TP.**

**Proposal 3: Agree to adopt the updated definitions of MI, HMI and Integrity Event in Section 3.1.**

**Proposal 4: Agree to adopt the AGV examples in Table 9.2.4.**

**Proposal 5: Agree to adopt the Rail text in Section 9.2.2.**

**Proposal 6: Agree to adopt the ‘KPIs and Use Cases’ TP as the baseline text for the TR.**

**Question 1: Do you agree with Proposals 1 to 6? If not, please identify the specific proposal(s) you want to discuss and why.**

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| vivo | Yes |  |
| Swift Navigation | Yes |  |
| OPPO |  | For P4 on IIoT, just wondering whether it is for GNSS-based integrity or not? Our comment in Phase-1 is to further check whether IIoT as typical indoor scenario is suitable for R17 focus on GNSS integrity. Sorry if any misunderstanding here. |
| Nokia | Yes | Reply to OPPO:Yes this is for GNSS integrity as IIoT could be outdoor as well. Some 3GPP documents such as TR 22.804 and TS 22.104 have indicated that mobile robots for future factories could operate in outdoor service areas. More details can be found in our Tdoc R2-2009760. |
| Xiaomi | Yes |  |
| Apple | Yes |  |
| InterDigital | Yes | We agree with the explanation provided by Nokia. Several outdoor use cases corresponding to IIoT (e.g. for logistics), which could use GNSS, are also described in Reference [22] (5G ACIA White Paper). |
| ZTE | Yes |  |
| ESA | Yes | Comments:* Section 9.2: Beside providing references to WAAS in support of positioning integrity in aviation, we suggest to also include references to other SBAS systems.
* As “positioning integrity” is the wording that has been adopted in the TR, include “Positioning” in the title of sections 9.1 and 9.1.1:
	+ 9.1          Positioning Integrity Overview – Background Information
	+ 9.1.1       Positioning Integrity Concepts
 |

# 3. PHASE 2 – Text Proposal

The following text proposal incorporates the Observations above.

*Start of Text Proposal*

# 2 References

[1] 3GPP TR 22.872: “Study on positioning use cases”.

[2] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[3] RP-202094: "Study on NR Positioning Enhancements".

[4] 3GPP TR 38.855: "Study on NR Positioning (Release 16)".

[5] R2-2006541, TP for Study on Positioning Integrity and Reliability, Swift Navigation, Deutsche Telekom, u-blox, Ericsson, Mitsubishi Electric, Intel Corporation, CATT, UIC.

[6] Zhu, N., Marais, J., Betaille, D., Berbineau, M., “GNSS Position Integrity in Urban Environments: A Review of Literature”, IEEE Transactions on Intelligent Transportation Systems, Vol. 19, No. 9, Sep 2018.

[7] European Space Agency, “Integrity”, Navipedia, 2018, <https://gssc.esa.int/navipedia/index.php/Integrity>.

[8] Reid, T., Houts, S., Cammarata, R., Mills, G., Agarwal, S., Vora, A., Pandey, G., “Localization Requirements for Autonomous Vehicles,” SAE International Journal of Connected and Automated Vehicles, Vol. 2, No. 3, pp. 173–190, Sep 2019.

[9] GSA-MKD-RD-UREQ-250283, “Report on Road User Needs and Requirements: Outcome of the European GNSS’ User Consultation Platform”, Issue/Rev: 2.0, 2019.

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[11] 5GAA, “White Paper – C-V2X Use Cases Methodology, Examples and Service Level Requirements, 2019.

[12] Global Positioning System Wide Area Augmentation System (WAAS) Performance Standard, Department of Transportation USA, Federal Aviation Authority, Edition 1, October 2008.

[13] International Civil Aviation Organization, “Annex 10 to the Convention on International Civil Aviation, Aeronautical Telecommunications: International Standards and Recommended Practices”, 2006.

[14] RTCA DO-178C, “Software Considerations in Airborne Systems and Equipment Certification,” 2011.

[15] DO-229D, RTCA, "RTCA DO-229D Minimum Operational Performance Standards for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment," 2013.

[16] SAE J3016, “Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems”, SAE International, 2018.

[17] 3GPP TS 33.501, “Security architecture and procedures for 5G system”.

[18] European GNSS Agency, “GNSS User Technology Report issue 3”, 2020.

[19] Air Force Research Laboratory, “IS-AGT-100 Chips Message Robust Authentication (Chimera)”, 2019.

[20] 3GPP TR 22.804, “Study on Communication for Automation in Vertical Domains”.

[21] 3GPP TS 38.305, “Stage 2 functional specification of User Equipment (UE) positioning in NG-RAN”.

[22] 5G ACIA White Paper, "5G for Automation in Industry: Primary use cases, functions and service requirements", July 2019.

[23] Working Group C (WG-C), “EU-U.S. Cooperation on Satellite Navigation”, ARAIM Technical Subgroup, Interim Report, Issue 1, December 2012.

[24] EGNOS Open Service (OS) Service Definition Document, European Commission, Version 2.3, 2017.

[25] Elliott D. Kaplan, Christopher J. Hegarty, “Understanding GPS/GNSS Principles and Applications” Third Edition, Artech House, 2017.

*Next Text proposal*

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

**Positioning Integrity:** A measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the LCS client when the positioning system does not fulfil the condition for intended operation.

**Integrity Availability:** The integrity availability is the percentage of time that the PL is below the required AL.

**Feared Event:** Feared Events are considered to be all possible events (i.e. of natural, systemic or operational nature) that can cause the computed position to deviate from the true position, regardless of whether a specific fault can be identified in one of the positioning systems or not.

**Target Integrity Risk (TIR):** The probability that the positioning error exceeds the Alert Limit (AL) without warning the user within the required Time-to-Alert (TTA).

NOTE: The TIR is usually defined as a probability rate per some time unit (e.g. per hour, per second or per independent sample).

**Alert Limit (AL):** The maximum allowable positioning error such that the positioning system is available for the intended application. If the positioning error is beyond the AL, the positioning system should be declared unavailable for the intended application to prevent loss of positioning integrity.

NOTE: When the AL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Alert Limit (HAL) or Vertical Alert Limit (VAL) respectively.

**Time-to-Alert (TTA):** The maximum allowable elapsed time from when the positioning error exceeds the Alert Limit (AL) until the function providing positioning integrity annunciates a corresponding alert.

**Misleading Information (MI):** A MI event occurs when, the positioning system being declared available, the positioning error exceeds the PL.

**Hazardous Misleading Information (HMI):** A HMI event occurs when, the positioning system being declared available, the positioning error exceeds the AL without annunciating an alert within the TTA.

**Integrity Event:** An Integrity Event occurs when the positioning system outputs HMI.

## 3.2 Symbols

## 3.3 Abbreviations

**AL Alert Limit**

**HAL Horizontal Alert Limit**

**HMI Hazardously Misleading Information**

**HPL Horizontal Protection Level**

**MI Misleading Information**

**PE Positioning Error**

**PL Protection Level**

**TIR Target Integrity Risk**

**TTA Time-to-Alert**

**VAL Vertical Alert Limit**

**VPL Vertical Protection Level**

*Next Text proposal*

9 Positioning integrity and reliability

9.1 Integrity Overview – Background Information

### 9.1.1 Integrity Concepts

The ability to navigate safely means users must trust their estimated position with a high degree of confidence. Trustworthiness of position is the study of positioning integrity, which is adapted from TR 22.872 [1] as follows:

**Positioning Integrity:** A measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the LCS client when the positioning system does not fulfil the condition for intended operation.

Positioning integrity monitoring[[3]](#footnote-3) is already supported by GNSS service providers, but there is no common standard for expanding the ecosystem of connected devices which can benefit from positioning integrity. This study investigates new integrity assistance data and procedures to be considered in LPP and associated specifications, to assist in quantifying positioning integrity for the positioning system.

#### 9.1.1.1 Accuracy and Integrity

To understand the necessity of introducing the concept of positioning integrity, it is important to understand how it differs from the more familiar concept of Accuracy.

Positioning accuracy and positioning integrity are related but separate concepts, and for many use cases, accuracy alone is insufficient to meet the requirements. Positioning devices and services are typically designed to report the distribution of errors that characterize the overall system performance, which is often specified as an error percentile representing the accuracy. For example, a road vehicle with an embedded UE positioning client may report a lane-level accuracy of <50cm 95th percentile. In this case, the UE is indicating that, based on all the computed positions, its estimated accuracy is better than 50 centimeters, 95% of the time. For the remaining 5%, the position error is unknown. In fact, these errors might reach 10s or 100s of meters due to multiple different error sources. The 5% of errors are essentially unbounded without any way to reliably validate their distribution. In the case of GNSS, these errors could include constellation geometry (i.e. Dilution of Precision), sharp atmospheric gradients or irregularities, and local receiver effects such as high measurement noise or multipath.

Each time a position is provided, positioning integrity can be used to quantify the trust on the provided position. Positioning integrity is therefore a method of bounding these errors and this can be done to a much higher confidence. For example, a Target Integrity Risk (TIR) of 10-7/hr translates to a 99.99999% probability that no hazardously misleading outputs occurred in a given hour of operation. The TIR sets the target for determining which feared events need to be monitored in order to meet the specified Alert Limit (AL) at this level of probability. A lower TIR introduces a wider range of threats (i.e. feared events) that need to be monitored to improve confidence in the estimated position. Erroneous position estimates which do not meet the positioning integrity criteria can then be omitted in the final positioning solution, allowing only the valid position estimates to be utilized, which also leads to higher accuracy.

#### 9.1.1.2 Integrity Key Performance Indicators (KPIs)

The following KPIs for positioning integrity are defined for the study:

**Target Integrity Risk (TIR):** The probability that the positioning error exceeds the Alert Limit (AL) without warning the user within the required Time-to-Alert (TTA).

NOTE: The TIR is usually defined as a probability rate per some time unit (e.g. per hour, per second or per independent sample).

**Alert Limit (AL):** The maximum allowable positioning error such that the positioning system is available for the intended application. If the positioning error is beyond the AL, the positioning system should be declared unavailable for the intended application to prevent loss of positioning integrity.

NOTE: When the AL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Alert Limit (HAL) or Vertical Alert Limit (VAL) respectively.

**Time-to-Alert (TTA):** The maximum allowable elapsed time from when the positioning error exceeds the Alert Limit (AL) until the function providing positioning integrity annunciates a corresponding alert.

**Integrity Availability:** The integrity availability is the percentage of time that the PL is below the required AL.

The relationship between the KPIs and the Protection Level (PL), and their impacts on the positioning solution are further examined below.

#### 9.1.1.3 Integrity Protection Level (PL)

The Protection Level (PL) is a real-time upper bound on the positioning error at the required degree of confidence, where the degree of confidence is determined by the TIR probability.

The PL is defined as follows:

**Protection Level:** The PL is a statistical upper-bound of the Positioning Error (PE) that ensures that, the probability per unit of time of the true error being greater than the AL and the PL being less than or equal to the AL, for longer than the TTA, is less than the required TIR, i.e. the PL satisfies the following inequality:

**Prob per unit of time [((PE> AL) & (PL<=AL)) for longer than TTA] < required TIR**

NOTE: When the PL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Protection Level (HPL) or Vertical Protection Level (VPL) respectively.

NOTE: A specific equation for the PL is not specified as this is implementation-defined. For the PL to be considered valid, it must simply satisfy the inequality above.

The PL is used to indicate the positioning system availability, as when the PL is greater than the AL, the system is considered unavailable (see Stanford Diagram below). The PL establishes a more rigorous upper bound on the positioning error by taking into consideration the additional feared events which have a lower occurrence (i.e. lower TIR) compared to the nominal events considered in the standard accuracy estimate alone. The lower the TIR, the more feared events that need to be considered.

Fault feared events are those which are intrinsic to the positioning system and typically caused by the malfunction of an element of the positioning system (e.g. constellation or ground network failures). Fault-free feared events occur when the positioning system inputs are erroneous, but the event is not caused by a malfunction of the positioning system. In the GNSS context for example, fault-free feared events include nominal effects experienced every day such as poor satellite geometry, larger atmospheric gradients, and signal interruption, all of which can degrade positioning performance without causing the system to fail. A common limitation of existing industry functional safety standards, as summarized in [5], is that only the fault conditions are considered. In practice, however, the fault-free conditions also have a material contribution to the total integrity risk budget and must therefore be monitored.

The PL is necessary to ensure all potential faults and fault-free events down to the required TIR are considered. It bounds the tails of the distribution with higher certainty (per unit of time) and provides a measure for ensuring only those positions whose positioning integrity has been validated within the TIR are included in the final positioning solution. By contrast, the standard accuracy estimate only considers a subset of feared events up to a nominal percentile (e.g. 2-sigma, 95%), based on the entire distribution of estimated position errors.

#### 9.1.1.4 Relationship between the PL and KPIs

The TIR is a design constraint for a positioning system and represents the probability that a positioning error exceeds the AL, but the positioning system fails to alert the user within the required period of time (i.e. TTA). In practice, the TIR is very small. For example, <10-7/hr TIR translates to one failure permitted every 10 million hours (equivalent to 1142 years approximately).

Positioning integrity system failures are known as Integrity Events and integrity event occurs when the positioning system outputs Hazardous Misleading Information (HMI). HMI occurs when, the positioning being declared available, the actual positioning error exceeds the AL without annunciating an alert within the required TTA. Misleading Information occurs when, the positioning system being declared available, the actual positioning error exceeds the PL. Typically, positioning systems are designed to tolerate some level of MI, provided the system can continue to operate safely within the AL. To properly monitor for integrity in the positioning system, both the fault and fault-free conditions which potentially lead to MI or HMI need to be characterized for the network and the UE.

Figure 9.1.1.4-A illustrates the concept of MI and HMI with respect to the KPIs, PL and PE.

 

**Figure 9.1.1.4-A:** Relationship between Positioning Error (PE), Protection Level (PL), Alert Limit (AL), MI and HMI [6].

A useful representation for interpreting the relationship between the positioning integrity KPIs and PL is the so-called Stanford Diagram [7] in Figure 9.1.1.4-B. It should be noted that the Positioning Error (PE) in this diagram is the difference between the true position and the estimated position, computed by the positioning device. In practice, the true position is not known.



**Figure 9.1.1.4-B:** Stanford Diagram for integrity events, adapted from [7][8].

Important observations can be made from Figure 9.1.1.4-B in the context of this study:

1. The conditions represented above the diagonal line (Nominal Operations, System Unavailable) mean the positioning system is operating as intended by correctly detecting when the system should or should not be available.
2. The conditions represented below the diagonal line mean the system is not operating as intended. These conditions are what the positioning integrity system is designed to protect against, i.e. by monitoring the necessary fault and fault-free events to protect against MI or HMI for a given TIR. This concept is further described:
	* The TIR is equivalent to the probability per unit time of HMI, corresponding to the red block in the Stanford Diagram. The rate of MI (corresponding to the orange region), while undesirable, does not contribute towards the TIR.

In practice, positioning integrity systems are designed to tolerate some level of MI or HMI for a period of time within the TTA, without exceeding the TIR. This framework underpins the PL definition in this study (Section 9.1.1.3) and is particularly important for systems with communication latency, such as 3GPP, given assistance data can be monitored and sent by the network (i.e. the basis of this study). Sufficient time is therefore needed to signal that a fault is present. There is nothing prohibiting the TTA being set to zero for instantaneous detection, however a grace period must be accommodated to allow some level of functionality to be offloaded to the network when the network is utilized. Hence, the TTA depends on the overall positioning integrity system design (including 3GPP and non-3GPP elements) and is specified by the positioning system owner (e.g. a vehicle manufacturer) alongside the TIR and AL.

1. Interpretations when the system is **available** (PL<AL):
* **Nominal Operations (PE<PL):** the solution is available and operating safely without an integrity event.
* **Misleading Information (PE>PL & PE<AL):** the solution is available but contains an MI integrity event due to PE>PL. It is still operating safely given PE does not exceed the AL.
* **Hazardous Misleading Information (PE>PL & PE>AL):** the solution is available but contains an HMI integrity event due to PE>AL. It is still declared safe (PL<AL) when it should not have been.
1. Interpretations when the system is **unavailable** (PL>AL):
* **System Unavailable, False Alert (PE<PL & PE<AL):** the solution is unavailable but is a false alert integrity event, given PE<AL.
* **System Unavailable (PE<PL & PE>AL):** the solution is unavailable and operating as intended without an integrity event given PE>AL was properly detected.
* **System Unavailable and Misleading (PE>PL & PE>AL):** the solution is unavailable and contains a MI (PE>PL) integrity event.

## 9.2 Use Cases

RAT-Independent GNSS positioning integrity monitoring has a long operational history in the field of civil aviation [12][13][14][15]. The positioning integrity framework examined in this study extends beyond aviation, to address a broader suite of use case and architectural considerations for the 3GPP system. These concepts are further illustrated by the use case descriptions and KPIs provided below, including a particular focus on safety-critical and liability-critical applications, requiring the capability to validate the estimated position with greater trust.

### 9.2.1 Automotive

#### 9.2.1.1 Road-Level Identification and Road-User Charging

Positioning integrity is a key input to determining whether a road vehicle is traveling on a highway or a neighbouring access road (e.g. a collector-distributor lane). For example, consider a manufacturer wanting to ensure their Advanced Driver-Assistance Systems (ADAS) only activates when the vehicle is on a highway. This requires the UE to determine with a high degree of positioning integrity which road the vehicle is traveling on, in order to avoid the potential for unintended ADAS functionality on the access road (or conversely to ensure the appropriate functionality has been activated on the highway). The road vehicle may also be subject to road-user charging with fees that vary depending which road is used, also requiring positioning integrity validation.

Consider an access road that is within 3 metres of a freeway, with a corresponding AL of 3 metres and TIR of 1 x10-7/hr specified by the vehicle manufacturer. The road vehicle connects to an positioning integrity service provider via the mobile network to request UE-Based positioning integrity assistance data. The assistance data is applied by the UE alongside its local positioning measurements in order to compute the real-time PL. So long as the PL remains below the AL, the positioning system is available and functioning as intended, and the road-level identification can be made safely. If the PL exceeds the AL, the impacted positioning system should be declared unavailable on the vehicle and a road-level determination is not possible. For example, a network-detected fault can be flagged in the positioning integrity assistance data, resulting in a larger PL computed by the UE.

Another important positioning integrity aspect to take into account in road-user charging and other applications (like pay how you drive insurances) is that, because of their intrinsic nature, they have to be robust against attempts to deceive the positioning system. In this kind of applications the driver of the vehicle may be motivated to alter the position of its own vehicle in order to avoid being charged. Hence, the positioning integrity of the vehicle position needs to be ensured by being able to detect these deception attempts, for example by employing anti-tamper equipment and by cross-checking different positioning sources.

#### 9.2.1.2 Lane-Level Identification

The same concepts and methods from 9.2.1.1 also apply to validating the lane in which the vehicle is traveling. Lane change warnings and manoeuvres are a crucial input to enabling various Levels of autonomy [16] which are illustrated in the 5GAA use case requirements [11], such as an AL of 1.5m and TIR of 1x10-7/hr or lower.

The ability to handle faults almost instantaneously on a road vehicle is absolutely critical in order to recover the situation and avoid a potential collision between lanes. The UE is responsible for monitoring localized events which need to be detected in the shortest time possible, i.e. ‘highly dynamic’ feared events (e.g. multipath, cycle slips and satellite feared events in the case of GNSS). The network is therefore used to monitor the low dynamic threats, which are less time-critical but still depend on a reliable communication channel with the UE. In the automotive and other 5G positioning use cases, the TTA is also far more stringent (e.g. 100ms in some cases) compared with an aviation TTA of 6 seconds (or slower) for precision approaches. Hence, the low latency of the 3GPP communications presents a strong synergy for supplying positioning integrity assistance data that is secure and assured.

Once again, the positioning system should remain available unless the PL exceeds the AL, in which case the system should be unavailable and the corresponding ADAS functionality on the vehicle disengaged. To avoid an integrity event, any feared event with an occurrence probability higher than the TIR (i.e. >1x10-7/hr) needs to be detected and mitigated within the TTA[[4]](#footnote-4). The UE application is typically responsible for issuing alerts to inform the preventative or remedial actions required by the positioning system.

If a feared event occurs at the network or UE, the positioning system should be capable of determining its effect on the PL relative to the AL, within the required TTA, such that the position reported by the UE remains fault-free (i.e. even if the fault-free position leads to the system being unavailable). The TTA therefore represents the ability of the system to recover before being impacted by a potential integrity event. For some use cases, the TTA may simply be set to zero depending on the implementation requirements.

### 9.2.2 Rail

 9.2.2.1 Safety-Critical Applications

**Automatic Train Protection** (ATP) applications are used to ensure that trains run safely and efficiently on the right tracks with appropriate speed. Automatic Train Protection aims to prevent a train proceeding beyond the point of danger and to prevent the speed of the train exceeding the permissible limit in the event of a driver error. It consists of the safe determination of position, speed and direction of train movement in order to supervise the safe movement of the train up to its stopping point. This application requires the combination of several functions (or lower level applications) which in turn are strongly dependent of the accurate and safe determination of position and speed of the trains. There are many ATP applications where positioning integrity could be employed, among them one can include Enhanced Odometry, Absolute Positioning, Cold Movement Detection, Train integrity and train length monitoring, Track Identification, Odometer Calibration, and Level Crossing Protection.

**Emergency Management** applications, like the trackside personnel protection (to protect personnel working on or close to the track from the trains using the network) and the door control supervision (to enable the opening of specific doors at particular stations), are also safety-critical applications where positioning integrity will improve the performances and reduce risks.

#### 9.2.2.1 Liability-Critical Applications

**Asset Management**. The accuracy and confidence on the position needed for the location of the assets in some cases can be demanding and requiring high precision and reliable surveying. Fixed asset management applications are linked with the railway environment, from the infrastructure surveying and structural monitoring to the trackside equipment. Rolling stock asset management applications are in charge of the vehicles that move on a railway including both powered and unpowered vehicles, for example locomotives, railroad cars, coaches, and wagons. Rolling stock applications include: fleet management, cargo monitoring, infrastructure charging, energy charging and hazardous cargo monitoring.

**Protection and Emergency Management Systems**. This group includes applications such as trackside personnel protection, management of emergencies and train warning systems. Management of emergencies can be greatly improved if an accurate, reliable and continuous location of the train is available, allowing the emergency teams to optimise their operations. Train warning systems are employed when some railways require a special warning to passengers on a platform when a train is approaching and is expected to pass the platform at a speed greater than a defined level. This application requires reliable details of train location, speed and other infrastructure data, and may result in an automatic station announcement via a public service broadcast.

**Traffic Management and Information Systems**. This group of applications includes traffic management systems (dispatching), but also on-board train monitoring and recording unit, hazardous cargo monitoring and infrastructure charging.

### 9.2.3 Industrial IoT

Editor’s note: Definition of the IIoT use cases is FFS and the examples in this study are limited to those requiring RAT-Independent GNSS positioning.

In contrast to consumer-oriented Internet of Things (IoT), Industrial IoT (IIoT) use cases predominantly focus on operational, safety, and financially beneficial applications of the IoT ecosystem for businesses, infrastructure, and various industries. IIoT positioning integrity/reliability requirements are essential given various safety, payment, and regulatory critical applications. There are many outdoor IIoT devices/UEs employing GNSS (RAT-independent positioning) in various industries that include, but not limited to: Construction, Agriculture/forestry/fishing (smart farming), Oil/Gas industries, and Smart cities (traffic, electric and water systems, waste management, public safety, schools) derived from [1][20]. An illustrative example relating to Automated Guided Vehicles (AGV) is provided below.

#### 9.2.3.1 Path and Zone Identification for AGV

Positioning integrity is a key input to determining whether an AGV such as a forklift, in a factory or an open space such as ports or construction buildings, is traveling on the narrow halls within lots of different machinery, aside from the demanding positioning accuracy, the trust needs to be assigned for the path and the zone of its movements. AGV not running into anything unexpectedly is something that needs to be assured. This requires that the AGV, which is the UE in this use-case, to determine with a high degree of positioning integrity which path it can travel within its defined work task. One can also consider that an industrial scenario can have several different zones in which different levels of positioning integrity can be defined, and hence depending on demand of the works in each zone the positioning methods and positioning integrity KPIs can be defined in respect to those. Once again, the positioning system should remain available unless the PL exceeds the AL, in which case the system should be unavailable and the corresponding AGV functionality on the vehicle is disengaged. The set AL for such use-case depends on how large and how densely equipped the factory is, and hence it is reasonable to assume that it can be set to some value between 0.5m to 3m depending on the controlled area use-case and demands. Further illustration of AGV, which requires support for positioning for tracking, routing and guiding is provided in [22].

### 9.2.4 Use Case Summary

Table 9.2.4 is adapted from [9][10] and supplemented by [8][11]. It summarises the typical KPI ranges to be expected on implementation for the Automotive and Rail categories. Importantly, the KPIs are illustrative only; KPIs are typically specified by the positioning system owner on implementation (e.g. a vehicle OEM), taking into consideration the 3GPP and non-3GPP components of the system.

**Table 9.2.4: KPI examples for the Automotive, Rail and IIoT use cases [8][9][10][11].**

NOTE: KPIs are defined by the service provider implementation.

|  |
| --- |
| **AUTOMOTIVE EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| **Safety-Critical Applications*** Warnings (red light, obstacle, queue, curve speed, blind spot lane change, pedestrians etc)
* Automated Driving (lane-level or better)
* Emergency Brake Assist
* Forward Collision Avoidance
 | Typical range: ≥10-8/hr to ≤10-6/hr | Typical range: ≥1.5m to <5m | Typically ranges from 100s of milliseconds to <10 seconds | Typically ranges from 95% to 99.9% or greater |
| **Payment Critical Applications*** Road User Charging (RUC)
* Pay Per Use Insurance
* Taxi Meter
* Parking Fee Calculation
 | Typical range: ≥10-6/hr to ≤10-4/hr | Typical range: ≥1.5m to <25m | Typically ranges from 95% to 99.9% or greater |
| **Smart Mobility** * Freight and Fleet Management
* Cargo/Asset Management
* Vehicle Access/Clearance
* Emergency Vehicle Priority
* Speed Limit Information
* In-Vehicle Signage
* Reduce Speed Warning
* Dynamic Ride Sharing
 |
| **RAIL EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| **Safety-Critical Applications** * Absolute Positioning
* Train Awakening
* Cold Movement Detector
* Track Identification
* Level Crossing Protection
* Train Integrity and Train Length Monitoring
 | Typical range: ≥10-9/hr to ≤10-8/hr | Typical range: ≥2.5m to <25m | Typically <7s | Typically ranges from 95% to 99.9% or greater |
| **Liability-Critical Applications** * Trackside Personal Protection
* Management of Emergencies
* Train Warning Systems
* Infrastructure Charging
* Hazardous Cargo Monitoring
* On-Board Train Monitoring and Recording Unit
* Traffic Management Systems
 | TBD | Typical range: ≥25m to <62.5m | Typically ranges from seconds to <30s | Typically ranges from 95% to 99.9% or greater |
| **IIOT EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| **AGV Applications** * Mobile device tracking
* Asset tracking
* Process automation
* Inbound logistics
 | Typical range: ≥10-8/hr to ≤10-1/hr | Typical range: ≥0.5m to <30m (vertical/horizontal) | Typically ranges from 100s of milliseconds to <10 seconds | Typically ranges from 95% to 99.9% or greater |

*End of Text proposal*

**Proposal 6: Agree to adopt the ‘KPIs and Use Cases’ TP as the baseline text for the TR.**

1. PHASE 1

# 1. Introduction (PHASE 1)

This document contains the questions and baseline TP for the following email discussion [1][2][3]:

[Post112-e][618][POS] Finalise integrity text proposals (Swift)

Scope: Refine the text proposals in R2-2010877/R2-2010878/R2-2010879.

Intended outcome: Agreeable TPs

Deadline: Long

The following documents should also be reviewed as part of this email discussion:

* Email Guideline - [Post112-e][618][POS] Integrity TPs [3]
* [618] Error Sources – PHASE 1 Draft TP [4]
* [618] Methodologies – PHASE 1 Draft TP [5]

# 2. KPIs and Use Cases (PHASE 1)

# 2.1 Terminology

# Positioning Integrity

As proposed by **T-Mobile**, the term ‘Integrity’ was updated to ‘Positioning Integrity’ in the definitions (R2-2010877 [2]) but the change also needs to be added throughout the remaining text. These updates are now included as track changes (i.e., positioning integrity) in the TP below. Please identify any additional sections which need updating.

# Alert Limit

As proposed by **Nokia**, the AL definition was updated in Section 3.1 (R2-2010877 [2]) by removing the words “”, however this change was not reflected in Section 9.1.1.2, which is now updated in the TP below.

# IIoT Use Case

Additional editorial comments were received by email from **Nokia** for the IIoT use case description under Section 9.2.3 of R2-2010877 [2] and these comments have now been reflected as track changes in the draft TP below.

# Feared Event

**T-Mobile and Nokia** raised questions online [1] and via email as to whether the term ‘feared event’ is suitable for definition within the 3GPP standards.

**Question 1: Do you agree with adopting the term ‘feared event’ in the context of positioning integrity? If not, what is your proposed alternative, and why?**

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| vivo | Yes |  |
| Swift Navigation | Yes | ‘Feared event’ is an established term in the context of positioning integrity [see R2-2006541]. We believe it is important to use the standard and well-established terms from the field of positioning integrity. The precise technical definition and interrelationship between these terms is critical for a thorough integrity analysis and replacing these with “common” meanings or phrases would not be sufficient.On the concerns about “feared events” implying that the operator may be aware of faults in the system and the potential liability concerns - this is precisely what the field of positioning integrity is trying to address. Positioning integrity concerns itself with mitigating risk in liability critical applications. Using different terminology to refer to feared events will not limit liability as these events exist regardless of the terminology used. For positioning integrity, it is better to be explicit and name the feared events which need to be mitigated to ensure a proper treatment of the topic and therefore a proper implementation without ambiguity in the terms. |
| Hexagon A&P | Yes |  |
| Nokia |  | We do have concerns as this term doesn’t sound so appropriate from telecom operator’s perspective. Nonetheless, we are okay to follow the majority views.  |
| InterDigital |  | In general, we do not have a strong objection against the term “feared event”. Alternatively, to be more 3GPP friendly, terms such as failure event or outage event may be considered  |
| CATT | Yes | We are fine to use the ‘feared event’ from the field of positioning integrity. |
| ZTE | Yes | Considering we have already defined feared event in the TR, we are fine for the feared event. |
| ESA | Yes | Is a standard term used in GNSS position integrity field – we should not re-invent things. |
| Xiaomi | Yes | We are fine for the term ‘feared event’. |
| u-blox | Yes | It is already widely adopted in the industry. |
| Huawei/HiSilicon | Yes | We agree with the adoption of “Feared event”, but we are wondering the relation between “feared event” and “failure mode/threat model” mentioned in the SID. |

# Hazardous

The term Hazardous was also flagged by **T-Mobile and Nokia** as being potentially problematic.

**Question 2: Do you agree with adopting the terms ‘hazardous’ in the context of positioning integrity? If not, what is your proposed alternative, and why?**

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| vivo | no | Hazardous should be kept for better understanding the relationship of KPI. |
| Swift Navigation | Yes | The term has now been removed from the AL definition (see 2.1.2 above) which hopefully resolves this concern. It is used for descriptive purposes elsewhere in the study (e.g. to describe the Stanford Diagram). |
| Hexagon A&P | Yes |  |
| Nokia |  | We are okay with the current definition of AL where the term “hazardous operation” is removed. |
| InterDigital |  | We are fine with the change to the AL definition proposed by Swift. Also, similar to our answer to Q1, alternative terms which are 3GPP friendly such as outage or erroneous may be considered instead of ‘hazardous’. |
| CATT | Yes | We are okay with the current definition the term removed from the AL above. |
| ZTE | No | We prefer to keep the hazardous.Because we have defined MI and HMI, for the unified perspective, we prefer to keep using “hazardous”. If RAN2 has to remove the hazardous, RAN2 may also need to re-name the “hazardous misleading information”. |
| ESA | YES | “Hazardous” can be removed except in the HMI term which is an establish concept in the field position integrity. |
| Xiaomi |  | If the description of Stanford Diagram will be updated with removing “hazardous”, we think YES, otherwise, NO.  |
| u-blox | Yes | Removing it from the AL definition is acceptable, but MI and HMI are accepted terms in the context of the Stanford diagram and we’d prefer to keep them in. |
| Huawei/HiSilicon | Yes | We are ok with the term since ‘hazardous’ has been widely used in GNSS aviation systems. |

# 2.2 Other Open Issues

**Question 3: Are there any open issues which have not been addressed by Questions 1 and 2? If so, please identify the issue(s), your reasoning and your proposed resolution.**

|  |  |  |
| --- | --- | --- |
| Company | Yes/No | Comments |
| vivo |  | The relationship between hazardous and feared event also need declare. |
| Swift Navigation | Yes | We think the study would benefit from additional definitions upfront in Section 3.1 for key terms already introduced in the text, including [adapted from R2-2006541]:**Fault:** A Feared Event that occurs intrinsic to the positioning system, i.e. caused by the malfunction of one of the elements of the positioning system.**Fault-free:** A Feared Event is considered Fault-free when it is not caused by a malfunction of the positioning system. Typically, Fault-free feared events are conditions when the positioning system inputs are erroneous e.g. a GNSS satellite failure or abnormal atmospheric condition.**Misleading Information (MI):** A MI event occurs when, the positioning system being declared available, the positioning error exceeds the PL but not the alert AL.**Hazardous Misleading Information (HMI):** A HMI event occurs when, the positioning system being declared available, the positioning error exceeds the AL without annunciating an alert within the TTA.**Integrity Event:** An Integrity Event occurs when the positioning system outputs MI or HMI. |
| Hexagon A&P | No |  |
| Nokia | Yes | The details of IIoT example in Table 9.2.4 is still missing. Here are some of our suggestions:**AGV Applications** * Mobile device tracking
* Asset tracking
* Process automation
* Inbound logistics

**TIR:** Typical range: ≥10-8/hr to ≤10-6/hr**AL:** Typical range: ≥0.5m to <3m**TTA:** Typically ranges from 100s of milliseconds to <10 seconds**Integrity Availability:** Typically ranges from 95% to 99.9% or greater |
| InterDigital | Yes | We agree with the suggestion from Nokia on listing of the AGV applications. We are also ok for including the example requirements for integrity KPIs in Table 9.2.4. Since AGVs can be operating in both horizontal and vertical dimensions (e.g. tracking assets on shelves, tracking flying drones, tracking robotic arms which may move up & down), we suggest the example range for AL to be indicated as follows: Vertical/Horizontal AL: Typical range: ≥0.5m to <3m |
| OPPO |  | For the addition of IIoT part, we are not so true: since this release is mainly for GNSS-based integrity, which seems not appropriate for IIoT (typically indoor scenario). |
| CATT |  | The PE is mentioned a lot in section 9.1.1.4 Relationship between the PL and KPIs, but there is no definition of PE in 3.1 Terms. |
| ZTE | Yes | We should define “additional” terms in section 3.1 before we use them in the TR.From our mind, the definition of *MI*, *HMI* and *Integrity event* should be added in the draft TR.We doubt whether RAN2 need to define the “*fault feared event”* or “*fault-free feared event”*. From our mind, these two definitions do not have much assistance about how to solve/ relief the influence of the feared events. The current positioning error Categories(clause 9.3.1) is fine for us after slightly explanation/modification. |
| ESA | Yes | 1. Nokia´s inputs should be added to the text
2. We have added in track-changes some text to railway section which otherwise would remain empty
3. TP is very long and is just a part of integrity items. For example we have checked current TR and we noticed that RAN1 was very concise. All information of current TP is extremely useful and it should not be discarded, we are just wondering if some can be moved to Annexes e.g., description of use cases?!
4. Some remarks as comments provided directly in text
 |
| u-blox | Yes | With respect to Swift’s definitions:**Misleading Information (MI):** A MI event occurs when, the positioning system being declared available, the positioning error exceeds the PL. (should not include AL in the definition because an HMI is a subset of MI.)**Integrity Event:** An Integrity Event occurs when the positioning system outputs HMI. (should not include MI even though in practice the implementation often assumes they are the same in order to be on the “safe side” of the risk probability.)Nokia’s inputs are useful, but with revised values:**TIR:** Typical range: ≥10-8/hr to ≤10-1/hr**AL:** Typical range: ≥0.5m to <30m (horizontal)However nothing has been mentioned about speed, heading, orientation or time which are also outputs of the positioning function in many applications. |
| Huawei/HiSilicon | No |  |

# 2.3 Draft Text Proposal

The baseline text below is from R2-2010877 [2] unless otherwise indicated in the track changes and comments.

*Start of Text Proposal*

# 2 References

[1] 3GPP TR 22.872: “Study on positioning use cases”.

[2] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[3] RP-202094: "Study on NR Positioning Enhancements".

[4] 3GPP TR 38.855: "Study on NR Positioning (Release 16)".

[5] R2-2006541, TP for Study on Positioning Integrity and Reliability, Swift Navigation, Deutsche Telekom, u-blox, Ericsson, Mitsubishi Electric, Intel Corporation, CATT, UIC.

[6] Zhu, N., Marais, J., Betaille, D., Berbineau, M., “GNSS Position Integrity in Urban Environments: A Review of Literature”, IEEE Transactions on Intelligent Transportation Systems, Vol. 19, No. 9, Sep 2018.

[7] European Space Agency, “Integrity”, Navipedia, 2018, <https://gssc.esa.int/navipedia/index.php/Integrity>.

[8] Reid, T., Houts, S., Cammarata, R., Mills, G., Agarwal, S., Vora, A., Pandey, G., “Localization Requirements for Autonomous Vehicles,” SAE International Journal of Connected and Automated Vehicles, Vol. 2, No. 3, pp. 173–190, Sep 2019.

[9] GSA-MKD-RD-UREQ-250283, “Report on Road User Needs and Requirements: Outcome of the European GNSS’ User Consultation Platform”, Issue/Rev: 2.0, 2019.

[10] GSA-MKD-RL-UREQ-250286, “Report on Rail User Needs and Requirements: Outcome of the European GNSS’ User Consultation Platform”, Issue/Rev: 2.0, 2019.

[11] 5GAA, “White Paper – C-V2X Use Cases Methodology, Examples and Service Level Requirements, 2019.

[12] Global Positioning System Wide Area Augmentation System (WAAS) Performance Standard, Department of Transportation USA, Federal Aviation Authority, Edition 1, October 2008.

[13] International Civil Aviation Organization, “Annex 10 to the Convention on International Civil Aviation, Aeronautical Telecommunications: International Standards and Recommended Practices”, 2006.

[14] RTCA DO-178C, “Software Considerations in Airborne Systems and Equipment Certification,” 2011.

[15] DO-229D, RTCA, "RTCA DO-229D Minimum Operational Performance Standards for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment," 2013.

[16] SAE J3016, “Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems”, SAE International, 2018.

[17] 3GPP TS 33.501, “Security architecture and procedures for 5G system”.

[18] European GNSS Agency, “GNSS User Technology Report issue 3”, 2020.

[19] Air Force Research Laboratory, “IS-AGT-100 Chips Message Robust Authentication (Chimera)”, 2019.

[20] 3GPP TR 22.804, “Study on Communication for Automation in Vertical Domains”.

[21] 3GPP TS 38.305, “Stage 2 functional specification of User Equipment (UE) positioning in NG-RAN”.

[22] 5G ACIA White Paper, "5G for Automation in Industry: Primary use cases, functions and service requirements", July 2019.

[23] Working Group C (WG-C), “EU-U.S. Cooperation on Satellite Navigation”, ARAIM Technical Subgroup, Interim Report, Issue 1, December 2012.

[24] R2-2009331 - Discussion on GNSS Integrity Errors, RAN2#112-e, Swift Navigation, Ericsson, Intel Corporation.

[25] Elliott D. Kaplan, Christopher J. Hegarty, “Understanding GPS/GNSS Principles and Applications” Third Edition, Artech House, 2017.

*Next Text proposal*

# 3 Definitions of terms, symbols and abbreviations

3.1 Terms

**Positioning Integrity:** A measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the LCS client when the positioning system does not fulfil the condition for intended operation.

**Integrity Availability:** The integrity availability is the percentage of time that the PL is below the required AL.

**Feared Event:** Feared Events are considered to be all possible events (i.e. of natural, systemic or operational nature) that can cause the computed position to deviate from the true position, regardless of whether a specific fault can be identified in one of the positioning systems or not.

**Target Integrity Risk (TIR):** The probability that the positioning error exceeds the Alert Limit (AL) without warning the user within the required Time-to-Alert (TTA).

NOTE: The TIR is usually defined as a probability rate per some time unit (e.g. per hour, per second or per independent sample).

**Alert Limit (AL):** The maximum allowable positioning error such that the positioning system is available for the intended application. If the positioning error is beyond the AL, the positioning system should be declared unavailable for the intended application to prevent loss of positioning integrity.

NOTE: When the AL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Alert Limit (HAL) or Vertical Alert Limit (VAL) respectively.

**Time-to-Alert (TTA):** The maximum allowable elapsed time from when the positioning error exceeds the Alert Limit (AL) until the function providing positioning integrity annunciates a corresponding alert.

3.2 Symbols

3.3 Abbreviations

**AL Alert Limit**

**HAL Horizontal Alert Limit**

**HMI Hazardously Misleading Information**

**HPL Horizontal Protection Level**

**MI Misleading Information**

**PE Positioning Error**

**PL Protection Level**

**TIR Target Integrity Risk**

**TTA Time-to-Alert**

**VAL Vertical Alert Limit**

**VPL Vertical Protection Level**

*Next Text proposal*

9 Positioning integrity and reliability

9.1 Integrity Overview – Background Information

9.1.1 Integrity Concepts

As positioning demands continue to increase, the scale and connectivity of emergent applications such as self-driving vehicles have necessitated a standards-based approach. More devices connecting to the 3GPP network means more users rely on the network being trustworthy and interoperable. The ability to navigate safely means users must trust their estimated position with a high degree of confidence. Trustworthiness of position is the study of positioning integrity, which is adapted from TR 22.872 [1] as follows:

**Positioning Integrity:** A measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the LCS client when the positioning system does not fulfil the condition for intended operation.

Positioning integrity monitoring[[5]](#footnote-5) is already supported by GNSS service providers, but there is no common standard for expanding the ecosystem of connected devices which can benefit from positioning integrity. This study investigates new integrity assistance data and procedures to be considered in LPP and associated specifications, to assist in quantifying positioning integrity for the positioning system.

9.1.1.1 Accuracy and Integrity

To understand the necessity of introducing the concept of positioning integrity, it is important to understand how it differs from the more familiar concept of Accuracy.

Positioning accuracy and positioning integrity are related but separate concepts, and for many use cases, accuracy alone is insufficient to meet the requirements. Positioning devices and services are typically designed to report the distribution of errors that characterize the overall system performance, which is often specified as an error percentile representing the accuracy. For example, a road vehicle with an embedded UE positioning client may report a lane-level accuracy of <50cm 95th percentile. In this case, the UE is indicating that, based on all the computed positions, its estimated accuracy is better than 50 centimeters, 95% of the time. For the remaining 5%, the position error is unknown. In fact, these errors might reach 10s or 100s of meters due to multiple different error sources. The 5% of errors are essentially unbounded without any way to reliably validate their distribution. In the case of GNSS, these errors could include constellation geometry (i.e. Dilution of Precision), sharp atmospheric gradients or irregularities, and local receiver effects such as high measurement noise or multipath.

Each time a position is provided, positioning integrity can be used to quantify the trust on the provided position. Positioning integrity is therefore a method of bounding these errors and this can be done to a much higher confidence. For example, a Target Integrity Risk (TIR) of 10-7/hr translates to a 99.99999% probability that no hazardously misleading outputs occurred in a given hour of operation. The TIR sets the target for determining which feared events need to be monitored in order to meet the specified Alert Limit (AL) at this level of probability. A lower TIR introduces a wider range of threats (i.e. feared events) that need to be monitored to improve confidence in the estimated position. Erroneous position estimates which do not meet the positioning integrity criteria can then be omitted in the final positioning solution, allowing only the valid position estimates to be utilized, which also leads to higher accuracy.

9.1.1.2 Integrity Key Performance Indicators (KPIs)

The following KPIs for positioning integrity are defined for the study:

**Target Integrity Risk (TIR):** The probability that the positioning error exceeds the Alert Limit (AL) without warning the user within the required Time-to-Alert (TTA).

NOTE: The TIR is usually defined as a probability rate per some time unit (e.g. per hour, per second or per independent sample).

**Alert Limit (AL):** The maximum allowable positioning error such that the positioning system is available for the intended application. If the positioning error is beyond the AL, the positioning system should be declared unavailable for the intended application to prevent loss of positioning integrity.

NOTE: When the AL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Alert Limit (HAL) or Vertical Alert Limit (VAL) respectively.

**Time-to-Alert (TTA):** The maximum allowable elapsed time from when the positioning error exceeds the Alert Limit (AL) until the function providing positioning integrity annunciates a corresponding alert.

**Integrity Availability:** The integrity availability is the percentage of time that the PL is below the required AL.

The relationship between the KPIs and the Protection Level (PL), and their impacts on the positioning solution are further examined below.

9.1.1.3 Integrity Protection Level (PL)

The Protection Level (PL) is a real-time upper bound on the positioning error at the required degree of confidence, where the degree of confidence is determined by the TIR probability.

The PL is defined as follows:

**Protection Level:** The PL is a statistical upper-bound of the Positioning Error (PE) that ensures that, the probability per unit of time of the true error being greater than the AL and the PL being less than or equal to the AL, for longer than the TTA, is less than the required TIR, i.e. the PL satisfies the following inequality:

**Prob per unit of time [((PE> AL) & (PL<=AL)) for longer than TTA] < required TIR**

NOTE: When the PL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Protection Level (HPL) or Vertical Protection Level (VPL) respectively.

NOTE: A specific equation for the PL is not specified as this is implementation-defined. For the PL to be considered valid, it must simply satisfy the inequality above.

The PL is used to indicate the positioning system availability, as when the PL is greater than the AL, the system is considered unavailable (see Stanford Diagram below). The PL establishes a more rigorous upper bound on the positioning error by taking into consideration the additional feared events which have a lower occurrence (i.e. lower TIR) compared to the nominal events considered in the standard accuracy estimate alone. The lower the TIR, the more feared events that need to be considered.

Fault feared events are those which are intrinsic to the positioning system and typically caused by the malfunction of an element of the positioning system (e.g. constellation or ground network failures). Fault-free feared events occur when the positioning system inputs are erroneous, but the event is not caused by a malfunction of the positioning system. In the GNSS context for example, fault-free feared events include nominal effects experienced every day such as poor satellite geometry, larger atmospheric gradients, and signal interruption, all of which can degrade positioning performance without causing the system to fail. A common limitation of existing industry functional safety standards, as summarized in [5], is that only the fault conditions are considered. In practice, however, the fault-free conditions also have a material contribution to the total integrity risk budget and must therefore be monitored.

The PL is necessary to ensure all potential faults and fault-free events down to the required TIR are considered. It bounds the tails of the distribution with higher certainty (per unit of time) and provides a measure for ensuring only those positions whose positioning integrity has been validated within the TIR are included in the final positioning solution. By contrast, the standard accuracy estimate only considers a subset of feared events up to a nominal percentile (e.g. 2-sigma, 95%), based on the entire distribution of estimated position errors.

9.1.1.4 Relationship between the PL and KPIs

The TIR is a design constraint for a positioning system and represents the probability that a positioning error exceeds the AL, but the positioning system fails to alert the user within the required period of time (i.e. TTA). In practice, the TIR is very small. For example, <10-7/hr TIR translates to one failure permitted every 10 million hours (equivalent to 1142 years approximately).

Positioning integrity system failures are known as Integrity Events. An integrity event occurs when the positioning system outputs Misleading Information (MI) or Hazardous Misleading Information (HMI). MI occurs when, the positioning system being declared available, the actual positioning error exceeds the PL but not the AL. Typically, positioning systems are designed to tolerate some level of MI, provided the system can continue to operate safely within the AL. HMI occurs when, the positioning being declared available, the actual positioning error exceeds the AL without annunciating an alert within the required TTA. To properly monitor for positioning integrity in the positioning system, both the fault and fault-free conditions which potentially lead to MI or HMI need to be characterized for the network and the UE.

Figure 9.1.1.4-A illustrates the concept of integrity events (MI, HMI) with respect to the KPIs, PL and PE.



**Figure 9.1.1.4-A:** Relationship between Positioning Error (PE), Protection Level (PL), Alert Limit (AL)
and the MI and HMI integrity events [6].

A useful representation for interpreting the relationship between the positioning integrity KPIs and PL is the so-called Stanford Diagram [7] in Figure 9.1.1.4-B. It should be noted that the Positioning Error (PE) in this diagram is the difference between the true position and the estimated position, computed by the positioning device. In practice, the true position is not known.



**Figure 9.1.1.4-B:** Stanford Diagram for integrity events, adapted from [7][8].

Important observations can be made from Figure 9.1.1.4-B in the context of this study:

1. The conditions represented above the diagonal line (Nominal Operations, System Unavailable) mean the positioning system is operating as intended by correctly detecting when the system should or should not be available.
2. The conditions represented below the diagonal line mean the system is not operating as intended. These conditions are what the positioning integrity system is designed to protect against, i.e. by monitoring the necessary fault and fault-free events to protect against MI or HMI for a given TIR. This concept is further described:
	* The TIR is equivalent to the probability per unit time of HMI, corresponding to the red block in the Stanford Diagram. The rate of MI (corresponding to the orange region), while undesirable, does not contribute towards the TIR.

In practice, positioning integrity systems are designed to tolerate some level of MI or HMI for a period of time within the TTA, without exceeding the TIR. This framework underpins the PL definition in this study (Section 9.1.1.3) and is particularly important for systems with communication latency, such as 3GPP, given assistance data can be monitored and sent by the network (i.e. the basis of this study). Sufficient time is therefore needed to signal that a fault is present. There is nothing prohibiting the TTA being set to zero for instantaneous detection, however a grace period must be accommodated to allow some level of functionality to be offloaded to the network when the network is utilized. Hence, the TTA depends on the overall positioning integrity system design (including 3GPP and non-3GPP elements) and is specified by the positioning system owner (e.g. a vehicle manufacturer) alongside the TIR and AL.

1. Interpretations when the system is **available** (PL<AL):
* **Nominal Operations (PE<PL):** the solution is available and operating safely without an integrity event.
* **Misleading Information (PE>PL & PE<AL):** the solution is available but contains an MI integrity event due to PE>PL. It is still operating safely given PE does not exceed the AL.
* **Hazardous Misleading Information (PE>PL & PE>AL):** the solution is available but contains an HMI integrity event due to PE>AL. It is still declared safe (PL<AL) when it should not have been.
1. Interpretations when the system is **unavailable** (PL>AL):
* **System Unavailable, False Alert (PE<PL & PE<AL):** the solution is unavailable but is a false alert integrity event, given PE<AL.
* **System Unavailable (PE<PL & PE>AL):** the solution is unavailable and operating as intended without an integrity event given PE>AL was properly detected.
* **System Unavailable and Misleading (PE>PL & PE>AL):** the solution is unavailable and contains a MI (PE>PL) integrity event.

9.2 Use Cases

RAT-Independent GNSS positioning integrity monitoring has a long operational history in the field of civil aviation [12][13][14][15]. The positioning integrity framework examined in this study extends beyond aviation, to address a broader suite of use case and architectural considerations for the 3GPP system. These concepts are further illustrated by the use case descriptions and KPIs provided below, including a particular focus on safety-critical and liability-critical applications, requiring the capability to validate the estimated position with greater trust.

Automotive and Rail have been highlighted as two industries which implement the most demanding safety-standards for positioning integrity. The following use case descriptions outline key integrity concepts and implications for users that require positioning integrity within their positioning system. An extended list of application examples is provided in the Use Cases Summary.

9.2.1 Automotive

9.2.1.1 Road-Level Identification and Road-User Charging

Positioning integrity is a key input to determining whether a road vehicle is traveling on a highway or a neighbouring access road (e.g. a collector-distributor lane). For example, consider a manufacturer wanting to ensure their Advanced Driver-Assistance Systems (ADAS) only activates when the vehicle is on a highway. This requires the UE to determine with a high degree of positioning integrity which road the vehicle is traveling on, in order to avoid the potential for unintended ADAS functionality on the access road (or conversely to ensure the appropriate functionality has been activated on the highway). The road vehicle may also be subject to road-user charging with fees that vary depending which road is used, also requiring positioning integrity validation.

Consider an access road that is within 3 metres of a freeway, with a corresponding AL of 3 metres and TIR of 1 x10-7/hr specified by the vehicle manufacturer. The road vehicle connects to an positioning integrity service provider via the mobile network to request UE-Based positioning integrity assistance data. The assistance data is applied by the UE alongside its local positioning measurements in order to compute the real-time PL. So long as the PL remains below the AL, the positioning system is available and functioning as intended, and the road-level identification can be made safely. If the PL exceeds the AL, the impacted positioning system should be declared unavailable on the vehicle and a road-level determination is not possible. For example, a network-detected fault can be flagged in the positioning integrity assistance data, resulting in a larger PL computed by the UE.

Another important positioning integrity aspect to take into account in road-user charging and other applications (like pay how you drive insurances) is that, because of their intrinsic nature, they have to be robust against attempts to deceive the positioning system. In this kind of applications the driver of the vehicle may be motivated to alter the position of its own vehicle in order to avoid being charged. Hence, the positioning integrity of the vehicle position needs to be ensured by being able to detect these deception attempts, for example by employing anti-tamper equipment and by cross-checking different positioning sources.

9.2.1.2 Lane-Level Identification

The same concepts and methods from 9.2.1.1 also apply to validating the lane in which the vehicle is traveling. Lane change warnings and manoeuvres are a crucial input to enabling various Levels of autonomy [16] which are illustrated in the 5GAA use case requirements [11], such as an AL of 1.5m and TIR of 1x10-7/hr or lower.

The ability to handle faults almost instantaneously on a road vehicle is absolutely critical in order to recover the situation and avoid a potential collision between lanes. The UE is responsible for monitoring localized events which need to be detected in the shortest time possible, i.e. ‘highly dynamic’ feared events (e.g. multipath, cycle slips and satellite feared events in the case of GNSS). The network is therefore used to monitor the low dynamic threats, which are less time-critical but still depend on a reliable communication channel with the UE. In the automotive and other 5G positioning use cases, the TTA is also far more stringent (e.g. 100ms in some cases) compared with an aviation TTA of 6 seconds (or slower) for precision approaches. Hence, the low latency of the 3GPP communications presents a strong synergy for supplying positioning integrity assistance data that is secure and assured.

Once again, the positioning system should remain available unless the PL exceeds the AL, in which case the system should be unavailable and the corresponding ADAS functionality on the vehicle disengaged. To avoid an integrity event, any feared event with an occurrence probability higher than the TIR (i.e. >1x10-7/hr) needs to be detected and mitigated within the TTA[[6]](#footnote-6). The UE application is typically responsible for issuing alerts to inform the preventative or remedial actions required by the positioning system.

If a feared event occurs at the network or UE, the positioning system should be capable of determining its effect on the PL relative to the AL, within the required TTA, such that the position reported by the UE remains fault-free (i.e. even if the fault-free position leads to the system being unavailable). The TTA therefore represents the ability of the system to recover before being impacted by a potential integrity event. For some use cases, the TTA may simply be set to zero depending on the implementation requirements.

9.2.2 Rail

9.2.2.1 Safety-Critical Applications

**Automatic Train Protection** (ATP) applications are used to ensure that trains run safely and efficiently on the right tracks with appropriate speed. Automatic Train Protection aims to prevent a train proceeding beyond the point of danger and to prevent the speed of the train exceeding the permissible limit in the event of a driver error. It consists of the safe determination of position, speed and direction of train movement in order to supervise the safe movement of the train up to its stopping point. This application requires the combination of several functions (or lower level applications) which in turn are strongly dependent of the accurate and safe determination of position and speed of the trains. There are many ATP applications where positioning integrity could be employed, among them one can include Enhanced Odometry, Absolute Positioning, Cold Movement Detection, Train integrity and train length monitoring, Track Identification, Odometer Calibration, and Level Crossing Protection.

**Emergency Management** applications, like the trackside personnel protection (to protect personnel working on or close to the track from the trains using the network) and the door control supervision (to enable the opening of specific doors at particular stations), are also safety-critical applications where positioning integrity will improve the performances and reduce risks.

9.2.2.1 Liability-Critical Applications

**Asset Management**. The accuracy and confidence on the position needed for the location of the assets in some cases can be demanding and requiring high precision and reliable surveying. Fixed asset management applications are linked with the railway environment, from the infrastructure surveying and structural monitoring to the trackside equipment. Rolling stock asset management applications are in charge of the vehicles that move on a railway including both powered and unpowered vehicles, for example locomotives, railroad cars, coaches, and wagons. Rolling stock applications include: fleet management, cargo monitoring, infrastructure charging, energy charging and hazardous cargo monitoring.

**Protection and Emergency Management Systems**. This group includes applications such as trackside personnel protection, management of emergencies and train warning systems. Management of emergencies can be greatly improved if an accurate, reliable and continuous location of the train is available, allowing the emergency teams to optimise their operations. Train warning systems are employed when some railways require a special warning to passengers on a platform when a train is approaching and is expected to pass the platform at a speed greater than a defined level. This application requires reliable details of train location, speed and other infrastructure data, and may result in an automatic station announcement via a public service broadcast.

**Traffic Management and Information Systems**. This group of applications includes traffic management systems (dispatching), but also on-board train monitoring and recording unit, hazardous cargo monitoring and infrastructure charging.

9.2.3 Industrial IoT

Editor’s note: Definition of the IIoT use cases is FFS and the examples in this study are limited to those requiring RAT-Independent GNSS positioning.

In contrast to consumer-oriented Internet of Things (IoT), Industrial IoT (IIoT) use cases predominantly focus on operational, safety, and financially beneficial applications of the IoT ecosystem for businesses, infrastructure, and various industries. IIoT positioning integrity/reliability requirements are essential given various safety, payment, and regulatory critical applications. There are many outdoor IIoT devices/UEs employing GNSS (RAT-independent positioning) in various industries that include, but not limited to: Construction, Agriculture/forestry/fishing (smart farming), Oil/Gas industries, and Smart cities (traffic, electric and water systems, waste management, public safety, schools) derived from [1][20]. An illustrative example relating to Automated Guided Vehicles (AGV) is provided below.

9.2.3.1 Path and Zone Identification for AGV

Positioning integrity is a key input to determining whether an AGV such as a forklift, in a factory or an open space such as ports or construction buildings, is traveling on the narrow halls within lots of different machinery, aside from the demanding positioning accuracy, the trust needs to be assigned for the path and the zone of its movements. AGV not running into anything unexpectedly is something that needs to be assured. This requires that the AGV, which is the UE in this use-case, to determine with a high degree of positioning integrity which path it can travel within its defined work task. One can also consider that an industrial scenario can have several different zones in which different levels of positioning integrity can be defined, and hence depending on demand of the works in each zone the positioning methods and positioning integrity KPIs can be defined in respect to those. Once again, the positioning system should remain available unless the PL exceeds the AL, in which case the system should be unavailable and the corresponding AGV functionality on the vehicle is disengaged. The set AL for such use-case depends on how large and how densely equipped the factory is, and hence it is reasonable to assume that it can be set to some value between 0.5m to 3m depending on the controlled area use-case and demands. Further illustration of AGV, which requires support for positioning for tracking, routing and guiding is provided in [22].

9.2.4 Use Case Summary

Table 9.2.4 is adapted from [9][10] and supplemented by [8][11]. It summarises the typical KPI ranges to be expected on implementation for the Automotive and Rail categories. Importantly, the KPIs are illustrative only; KPIs are typically specified by the positioning system owner on implementation (e.g. a vehicle OEM), taking into consideration the 3GPP and non-3GPP components of the system.

**Table 9.2.4: KPI examples for the Automotive, Rail and IIoT use cases [8][9][10][11].**

**(NOTE: KPIs are defined by the service provider implementation)**

|  |
| --- |
| **AUTOMOTIVE EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| **Safety-Critical Applications*** Warnings (red light, obstacle, queue, curve speed, blind spot lane change, pedestrians etc)
* Automated Driving (lane-level or better)
* Emergency Brake Assist
* Forward Collision Avoidance
 | Typical range: ≥10-8/hr to ≤10-6/hr | Typical range: ≥1.5m to <5m | Typically ranges from 100s of milliseconds to <10 seconds | Typically ranges from 95% to 99.9% or greater |
| **Payment Critical Applications*** Road User Charging (RUC)
* Pay Per Use Insurance
* Taxi Meter
* Parking Fee Calculation
 | Typical range: ≥10-6/hr to ≤10-4/hr | Typical range: ≥1.5m to <25m | Typically ranges from 95% to 99.9% or greater |
| **Smart Mobility** * Freight and Fleet Management
* Cargo/Asset Management
* Vehicle Access/Clearance
* Emergency Vehicle Priority
* Speed Limit Information
* In-Vehicle Signage
* Reduce Speed Warning
* Dynamic Ride Sharing
 |
| **RAIL EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| **Safety-Critical Applications** * Absolute Positioning
* Train Awakening
* Cold Movement Detector
* Track Identification
* Level Crossing Protection
* Train Integrity and Train Length Monitoring
 | Typical range: ≥10-9/hr to ≤10-8/hr | Typical range: ≥2.5m to <25m | Typically <7s | Typically ranges from 95% to 99.% or greater |
| **Liability-Critical Applications** * Trackside Personal Protection
* Management of Emergencies
* Train Warning Systems
* Infrastructure Charging
* Hazardous Cargo Monitoring
* On-Board Train Monitoring and Recording Unit
* Traffic Management Systems
 | TBD | Typical range: ≥25m to <62.5m | Typically ranges from seconds to <30s | Typically ranges from 95% to 99.9% or greater |
| **IIOT EXAMPLES** |
| **APPLICATION CATEGORIES** | **TIR** | **AL** | **TTA** | **Integrity Availability** |
| FFS | FFS | FFS | FFS | FFS |

*End of Text proposal*

# References

[1] R2-xxxxxx [RAN2-112-e-Positioning-Relay-2020-11-13-1745\_eom.docx](https://www.3gpp.org/ftp/tsg_ran/WG2_RL2/TSGR2_112-e/Inbox/Chairmans_Notes/RAN2-112-e-Positioning-Relay-2020-11-13-1745_eom.docx),

<https://www.3gpp.org/ftp/tsg\_ran/WG2\_RL2/TSGR2\_112-e/Inbox/Chairmans\_Notes>

[2] R2-2010877 TP on Integrity KPIs, Concepts, Use Cases, Swift Navigation.

[3] [Email Guideline - [Post112-e][618][POS] Integrity TPs](https://www.3gpp.org/ftp/Email_Discussions/RAN2/%5BRAN2%23112-e%5D/%5BPost112-e%5D%5B618%5D%5BPOS%5D%20Integrity%20text%20proposals%20%28Swift%29/)

[4] [[618] Error Sources – PHASE 2 Draft TP](https://www.3gpp.org/ftp/Email_Discussions/RAN2/%5BRAN2%23112-e%5D/%5BPost112-e%5D%5B618%5D%5BPOS%5D%20Integrity%20text%20proposals%20%28Swift%29/PHASE%202/Error%20Sources)

[5] [[618] Methodologies – PHASE 2 Draft TP](https://www.3gpp.org/ftp/Email_Discussions/RAN2/%5BRAN2%23112-e%5D/%5BPost112-e%5D%5B618%5D%5BPOS%5D%20Integrity%20text%20proposals%20%28Swift%29/PHASE%202/Methodologies)

1. A monitor is used to detect the feared events that occur more frequently than is acceptable to meet the TIR, i.e., the monitor’s purpose is to reduce the likelihood that feared events go undetected. [↑](#footnote-ref-1)
2. NOTE: If the lane-level requirement was simply specified by the accuracy estimate (e.g., <1.5m at the 95th percentile), 5% of the estimated positions may still be impacted by feared events which far exceed the required AL, potentially leading to an integrity event. Positioning integrity KPIs are instead used to define probabilities of failure over a given period of time rather than relying on the combined statistical distribution of the estimated positions (which are potentially contaminated by fault and fault-free events that go undetected). The positioning integrity methodologies allow an positioning integrity risk to be allocated based on the probability of occurrence for each feared event, and then quantified as a contribution to the total TIR. This ensures only the integrity-validated positions are included in the positioning estimate, meaning the nominal accuracy should be easily achieved. [↑](#footnote-ref-2)
3. A monitor is used to detect the feared events that occur more frequently than is acceptable to meet the TIR, i.e. the monitor’s purpose is to reduce the likelihood that feared events go undetected. [↑](#footnote-ref-3)
4. NOTE: If the lane-level requirement was simply specified by the accuracy estimate (e.g. <1.5m at the 95th percentile), 5% of the estimated positions may still be impacted by feared events which far exceed the required AL, potentially leading to an integrity event. Positioning integrity KPIs are instead used to define probabilities of failure over a given period of time rather than relying on the combined statistical distribution of the estimated positions (which are potentially contaminated by fault and fault-free events that go undetected). The positioning integrity methodologies allow an positioning integrity risk to be allocated based on the probability of occurrence for each feared event, and then quantified as a contribution to the total TIR. This ensures only the integrity-validated positions are included in the positioning estimate, meaning the nominal accuracy should be easily achieved. [↑](#footnote-ref-4)
5. A monitor is used to detect the feared events that occur more frequently than is acceptable to meet the TIR, i.e. the monitor’s purpose is to reduce the likelihood that feared events go undetected. [↑](#footnote-ref-5)
6. NOTE: If the lane-level requirement was simply specified by the accuracy estimate (e.g. <1.5m at the 95th percentile), 5% of the estimated positions may still be impacted by feared events which far exceed the required AL, potentially leading to an integrity event. Positioning integrity KPIs are instead used to define probabilities of failure over a given period of time rather than relying on the combined statistical distribution of the estimated positions (which are potentially contaminated by fault and fault-free events that go undetected). The positioning integrity methodologies allow an positioning integrity risk to be allocated based on the probability of occurrence for each feared event, and then quantified as a contribution to the total TIR. This ensures only the integrity-validated positions are included in the positioning estimate, meaning the nominal accuracy should be easily achieved. [↑](#footnote-ref-6)