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PROBABILITY-OF-OCCURRENCE MODEL FOR GNSS PNT UTILISATION RISK ASSESSMENT FACILITATES GNSS APPLICATION DEVELOPMENTS IN THE FIELDS OF AVIATION AND MARITIME

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- Content of presentation

- Introduction
- Hypothesis
- Material
- Method
- Concept/method demonstration
- Discussion
- Conclusion

- Introduction

- Global Navigation Satellite System (GNSS) as a component of national infrastructure & application enabler
- GNSS PNT performance presented for ideal case of utilisation
- GNSS applications requires GNSS positioning performance description -> embedded in GNSS application Quality of Service (QoS)
- What is the risk of GNSS positioning performance failure in the provision of positioning performance (accuracy) required by GNSS application?

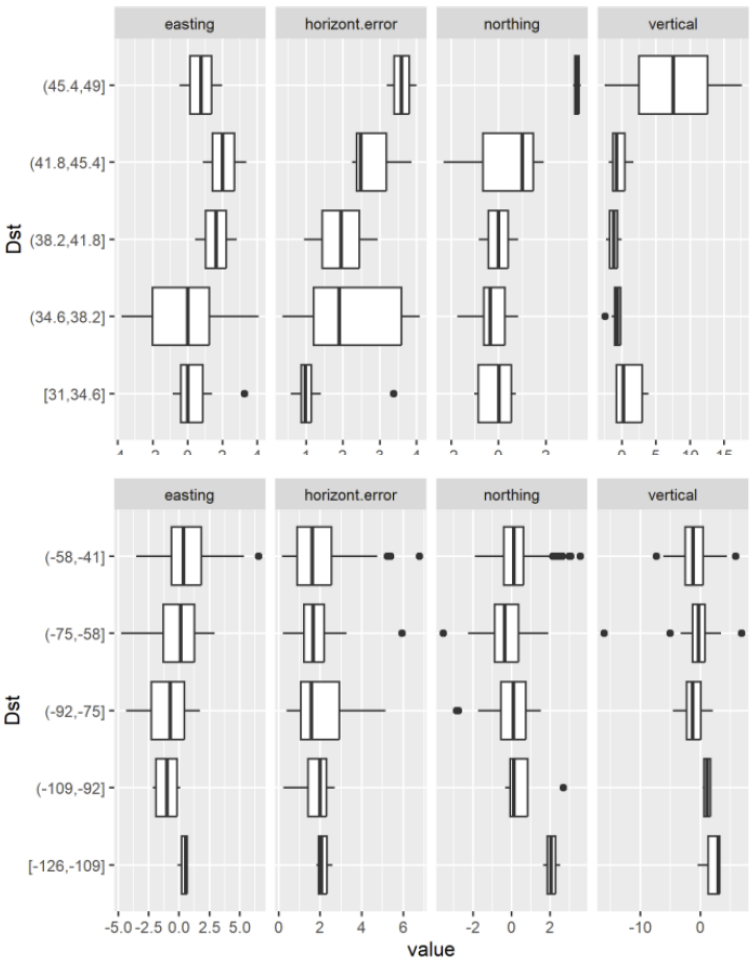
- Research hypothesis

- Sufficiently large dataset reflects the long-term statistical behaviour of GNSS positioning errors + proportional frequency of appearance of disturbing events -> a probabilistic model of the risk of GNSS positioning accuracy failure to meet the QoS requirements of a specific GNSS application

- Material (1/2)

- The sufficiently large dataset is available that reflects the long-term statistical behaviour of GNSS positioning errors -> continuous GNSS pseudorange observations at reference stations of International GNSS Service (IGS)
- This research utilises 365 days of GNSS pseudorange observations at Iqualuit, Canada
- The case of single-frequency GPS positioning errors, derived from GPS pseudorange observations, as observed in polar regions (Iqualuit)

- Material (2/2)
- Statistical analysis of horizontal GPS positioning error of a commercial-grade single-frequency GPS receiver



GPS horizontal error [m]	No. of observations in 2014	Mean	Median	Variance
Total	1019769	1.9549	1.6300	4.89951
Dst > 30 nT	24	2.0077	1.5496	1.629124
Dst < -40 nT	222	1.8110	1.6709	1.328492

Compared with General	t-test, p-value, H0: means are equal	F-test, p-value, H0: variances are equal
Dst > 30 nT	0.8411	0.00227
Dst < -40 nT	0.06421	< 2.2e-16

- Method (1/2)

- A single-function probabilistic model of the risk of GNSS positioning accuracy failure to meet the QoS requirements of a specific/targeted GNSS application -> **Probability of Occurrence (PoO) model**

- GPS/GNSS Probability of Occurrence (PoO) risk index is defined based on empirical identification of the GPS/GNSS positioning degradation

- Method (2/2)
- Probability density function $f_X(x)$ of statistical variable X

$$F_X(x) = P(X = x), F : \mathbb{R} \to [0,1]$$

- Cumulative distribution function (CDF) $F_X(x)$ is defined as the function that returns the probability that X will acquire the value less then, or equal to x

$$F_X(x) = P(X \le x), F : \mathbb{R} \to [0,1] = \int_{-\infty}^{x} f_X(x)\,dx$$

- Complementary cumulative distribution function (CCDF), or tail distribution, is derived from the cumulative distribution function

$$\bar{F}_X(x) = P(X > x) = 1 - F_X(x)$$

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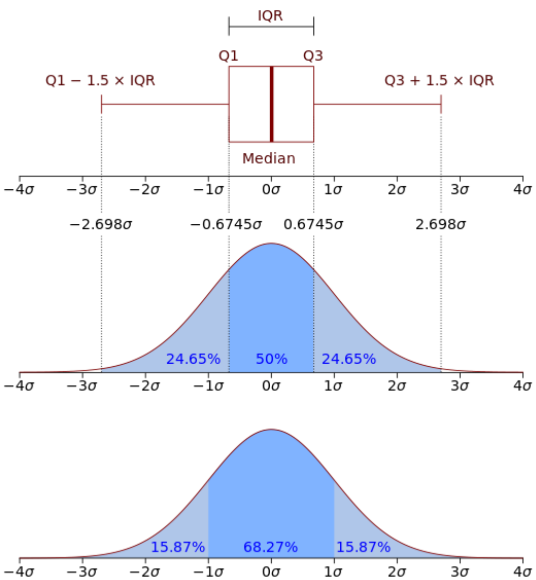
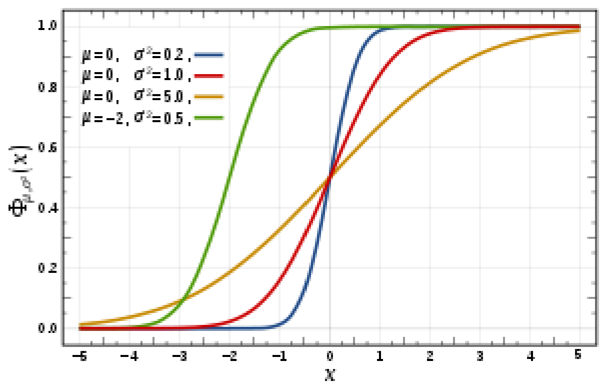


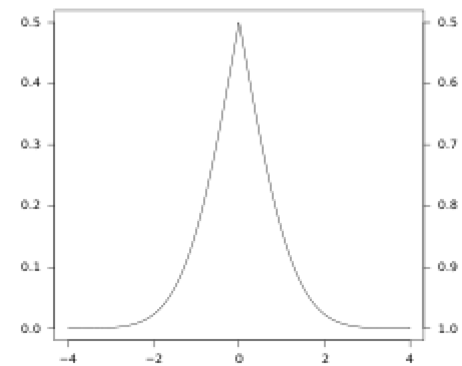
Source:
https://en.wikipedia.org/wiki/Probability_density_function

PDF



Source:
https://en.wikipedia.org/wiki/Cumulative_distribution_function

CDF



Source:
https://en.wikipedia.org/wiki/Cumulative_distribution_function#Complementary_cumulative_distribution_function_(tail_distribution)

CCDF

- Concept/method demonstration

- Scenario: polar regions, single-frequency commercial-grade GPS receiver, GPS application with defined QoS
- PoO GPS risk model developed on GPS postioning error estimates derived from experimental GPS pseudorange observations in polar region in 2014

$$P_{risk} = f\left(requested\ horizontal\ accuracy\right)$$

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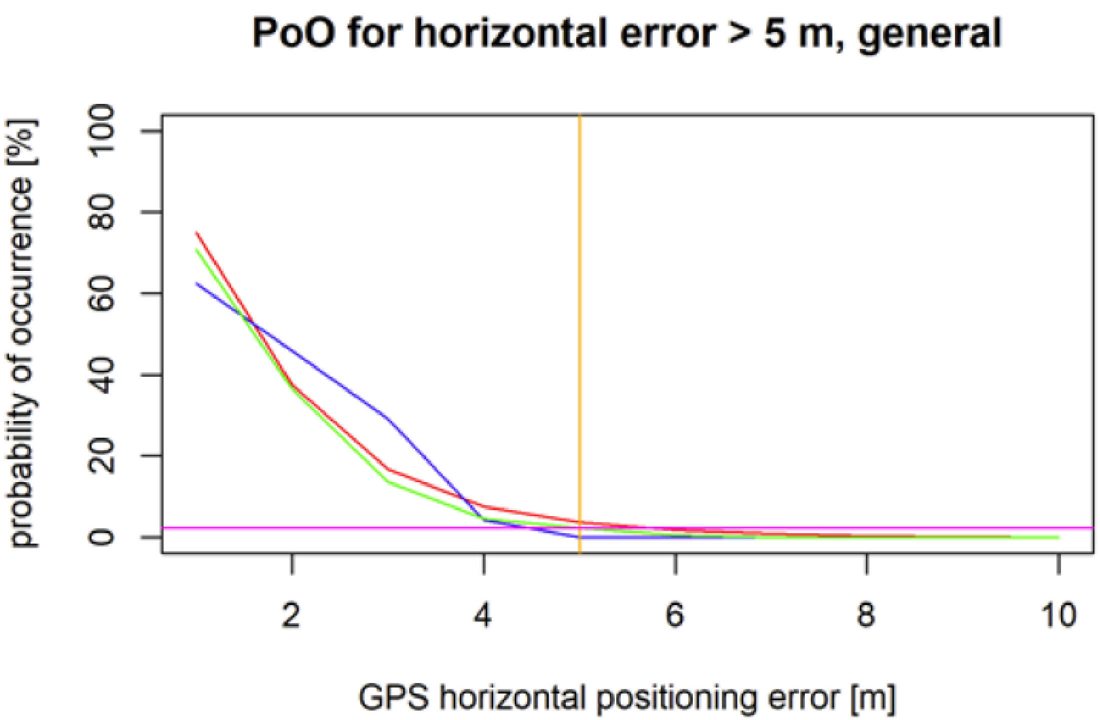
- Concept/method demonstration

- A specific GPS-based application should define its request for the highest acceptable horizontal GPS positioning error
- Example: GPS application requires that GPS positioning error should not exceed 5 m



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Source:https://www.euspa.europa.eu/sites/default/files/report_on_maritime_user_needs_and_requirements.pdf

Table 88: Port authorities' interest in inte

Application	Horizontal accuracy in A 22/Res.915
Navigation in ports	1 metre
Tugs and pushers operations	1 metre
General port approaches	10 metres
Aids to navigation management	1 metre

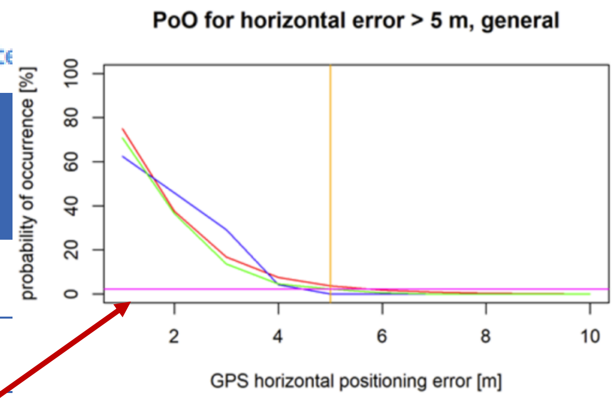

Table 90: e-GNSS performance requirements for autonomous vessels according to survey results.

Performance parameter	Oceanic deep-sea navigation	Coastal navigation
Horizontal accuracy 95%	<15m	<5m
Continuity (over 15 minutes)	$1{\cdot}1\text{x}10^{-5}$	$1{\cdot}1\text{x}10^{-6}$
AL	<28m	<12,5m
TTA	<8s	<6s
Integrity risk	$1{\cdot}1\text{x}10^{-6}$	1·1x10-7
Availability	99.8%	99.8%

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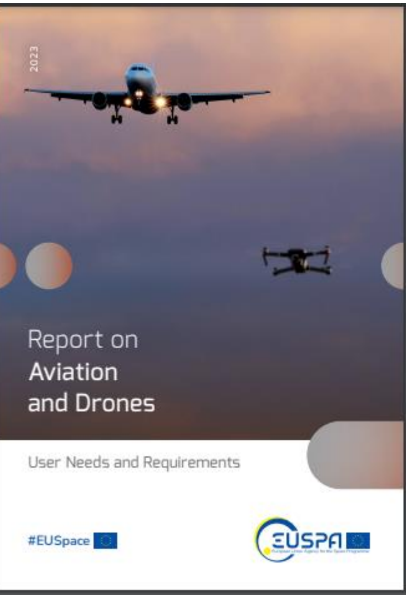

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity	Time-to-alert	Continuity	Availability
En-route	3.7 km (2.0 NM)	N/A	$1 - 1 \times 10^{-7}$/h	5 min	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1 - 1 \times 10^{-7}$/h	15 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1 - 1 \times 10^{-7}$/h	10 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	$1 - 2 \times 10^{-7}$ in any approach	10 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Category I precision approach (Note 7)	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft) (Note 6)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999

Figure 3: GNSS signal in space performance requirements – ICAO Annex 10 Vol I

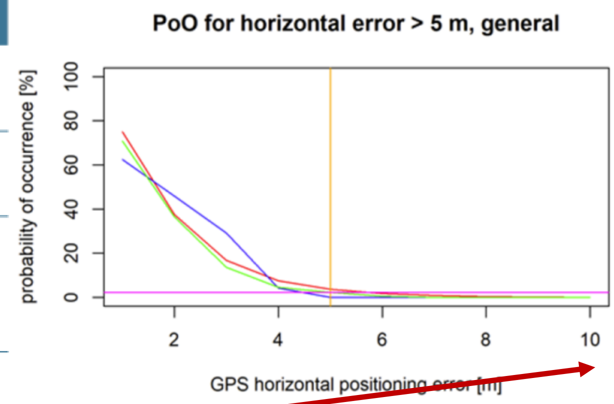

Table 3: Nav equipment (GNSS receiver) performance requirements for Drone en-route PBN[9]

Operation	Hor (m) NSE(95%)	Ver (m) NSE(95%)	Integrity[10]	TTA (s)	Alert limits (m)	Continuity	Availability
SAIL 3	3 - 8	4 - 13	1 -1E-4 /h	1 – 3	HAL: 25 -27 (fixed wing) 10 - 14 (rotary) VAL: 12 - 22 (fixed wing) 7 - 23 (rotary)	1 - 1E-4 /h	0.9999
SAIL 4	3 - 8	4 - 13	1 -1E-5 /h	1 - 3	HAL: 25 -27 (fixed wing) 10 - 14 (rotary) VAL: 12 - 22 (fixed wing) 7 - 23 (rotary)	1 - 1E-4 /h	0.9999

NOTE: *The performance characteristics presented in this table are sufficient to deliver navigation performance equivalent to a RNP 26/16 m for fixed wing and RNP 12/14 m for rotorcraft due to improved FTE for rotorcraft*

Source:
https://www.euspa.europa.eu/sites/default/files/report_on_aviation_and_drones_user_needs_and_requirements.pdf

- Discussion

- The proposed method, and PoO model demonstrated in the proof-of-principle scenario, may be generalised towards any positioning indicator requested, as well as to utilisation multiple GNSS position estimation.
- GPS application operator and user may consider implementation and operation of a redundant positioning system in a confined area (port) to overcome the risk, or the utilisation of integrated navigation (for example, GPS+INS), for the period of degraded GPS positioning performance.

- Conclusion

- This research proposes a single-function probabilistic model of the risk of GNSS positioning accuracy failure to meet the QoS requirements of a specific/targeted GNSS application -> Probability of Occurrence (PoO) model

- Recommendations

  - 1. Consideration of development & utilisation of a method of the Probability of Occurrence (PoO) model of GPS/GNSS application utilisation, especially in aviation and maritime.
  - 2. Assemblage of a year-long massive databases of GPS positioning errors presented in the open-source access manner.
  - 3. Fulfillment of, and support to, UN Sustainable Development Goals.
  - 4. Facilitation of international collaboration of GNSS PNT performance observation collection and risk analysis in various conditions of use, applications, and influencing phenomena.
  - 5. Utilisation of open source framework, such as R, for PoO model development and validation


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with a cordial invitation to:
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Baška, Krk Island, Croatia
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