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Operational GNSS Integrity

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Outline

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- GNSS integrity inherited from aviation
- GNSS integrity in marine operations
- Theory vs. real life
- Accuracy vs. integrity
- Conclusion

INTRODUCTION

The Answer to One Simple Question:

Can I trust my GNSS data?

Or Did You Really Mean…

- Can I trust the GNSS data sent from the GNSS satellite?
- Can I trust the GNSS corrections from the service provider?
- Can I trust the GNSS data from my receiver?
- Can I trust the GNSS data received by the DP?
- Can I trust that the DP is making the right decisions out of the GNSS data?
- Can I trust the GNSS data used in SIMOPS?

And The Answer Is:

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NO! ← **Maybe…** → **YES!**

Mostly no… **Mostly yes…**

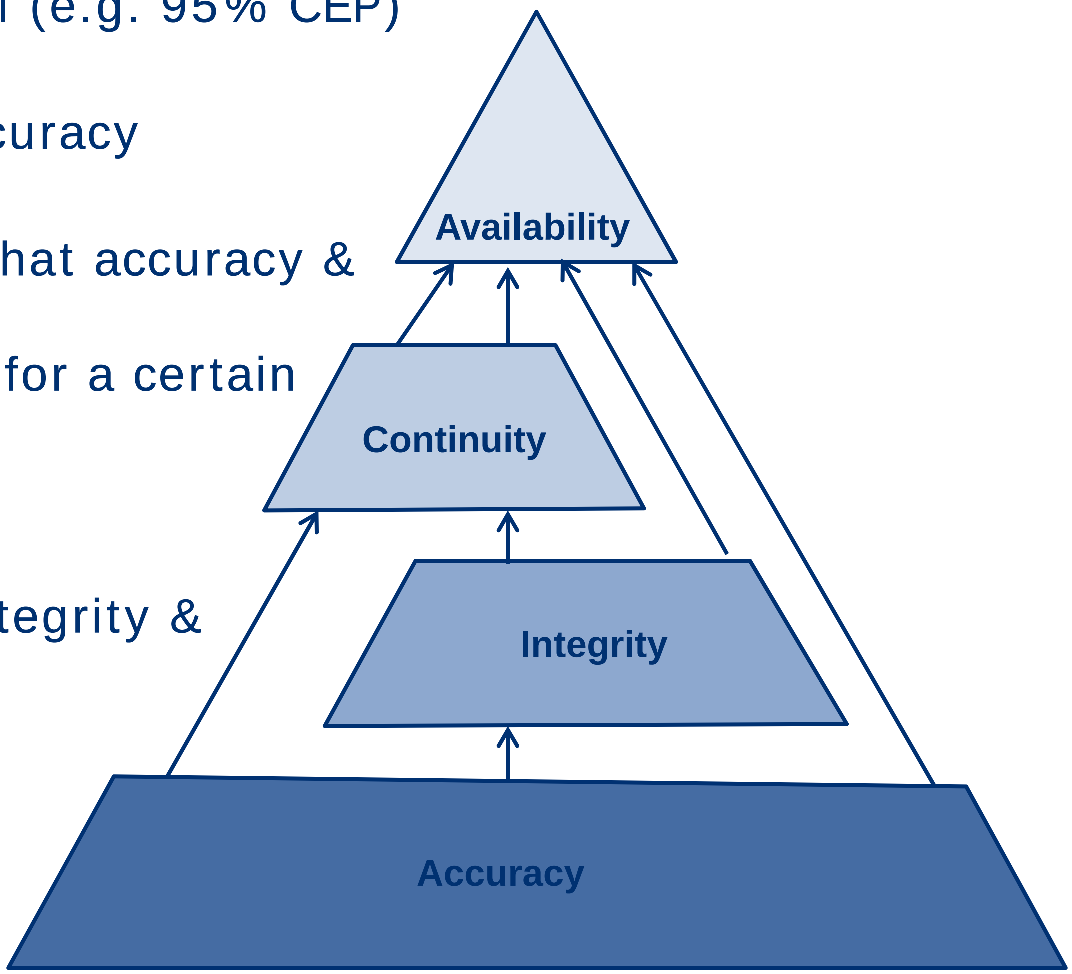
Almost always no… **Almost always yes…**

The developer’s Big Hairy Audacious Goal: Get as close to YES as possible!

GNSS PERFORMANCE

GNSS Navigation Performance Pyramid

- Accuracy at confidence level (e.g. 95% CEP)
- Integrity given a certain accuracy
- Continuity: the probability that accuracy & integrity will be maintained for a certain period into the future
- Availability of accuracy & integrity & continuity



Or More Precisely

- Accuracy is the difference between the position estimated by the navigation sensor and the true position of the vessel which is only exceeded 5% of the time in the absence of system failures.
- Integrity and continuity, address performance of the navigation system in the presence of failures or rare natural events. Integrity measures the ability of the system to protect the user from inaccurate position estimates in a timely fashion. Continuity measures the navigations system's ability to complete an operation without raising an alarm. These are the instantaneous metrics of navigation safety and are computed at e.g. 1 Hz.
- Integrity risk is defined as the probability that the error exceeds Alert Limit and the navigation system alert is silent beyond the time-to-alarm. On the other hand, continuity risk is defined as the probability that the navigation system alarm will drop during the operation. These are competing constraints on the system; integrity failures shall not lead to Hazardously Misleading Information favouring a small alert limit but continuity failures lead to false alarms favouring a large alert limit.
- The final metric is availability which emphasizes the operational economy of the navigation system. It is computed as the fraction of time the system is providing position fixes to the specified level of accuracy, integrity and continuity

GNSS INTEGRITY INHERITED FROM AVIATION

GNSS Integrity

- Alarm limit — If the position error exceeds a certain limit in meters I want to know
- Integrity risk — The probability that the position error exceeds the limit without me knowing
- Time-to-alarm — The time in seconds from the position error exceeds the limit until someone let me know

International Civil Aviation Organization

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Annex 10 — Aeronautical Communications *Volume I*

Table 3.7.2.4-1 Signal-in-space performance requirements

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity (Note 2)	Time-to-alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
En-route	3.7 km (2.0 NM) (Note 6)	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)	$1 - 2 \times 10^{-7}$ per approach	10 s	$1 - 8 \times 10^{-6}$ in any 15 s	0.99 to 0.999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1 - 2 \times 10^{-7}$ per approach	6 s	$1 - 8 \times 10^{-6}$ in any 15 s	0.99 t 0.999
Category I precision approach (Note 8)	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft) (Note 7)	$1 - 2 \times 10^{-7}$ per approach	6 s	$1 - 8 \times 10^{-6}$ in any 15 s	0.99 t 0.999

Typical operation	Horizontal alert limit	Vertical alert limit
En-route (oceanic/continental low density)	7.4 km (4 NM)	N/A
En-route (continental)	3.7 km (2 NM)	N/A
En-route, Terminal	1.85 km (1 NM)	N/A
NPA	556 m (0.3 NM)	N/A
APV-I	40 m (130 ft)	50 m (164 ft)
APV- II	40.0 m (130 ft)	20.0 m (66 ft)
Category I precision approach	40.0 m (130 ft)	15.0 m to 10.0 m (50 ft to 33 ft)

Category I (CAT I) – A precision instrument approach and landing with a decision height not lower than 200 feet (61 m) above touchdown zone elevation and with either a visibility not less than 800 meters (2,600 ft) or a runway visual range not less than 550 meters (1,800 ft).

GNSS INTEGRITY IN MARINE OPERATIONS

Lazy days in aviation…

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- One type of operation (landing)
- Lands on an airfields only
- Relaxed accuracy requirements
- Well defined antenna location and installation
- Certified equipment
- No (or little) multipath
- Low risk of interference / spoofing
- Little GNSS signal obstruction
- No other aircrafts coming too close
- Can go away if weather is too bad

In offshore operations your are not always this lucky!…

http://www.nrk.no/nyheter/okonomi/1.7375207

Marine Operations Open New Challenges

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RAIM is needed for operational integrity

- RAIM – Receiver Autonomous Integrity Monitoring
- The receiver uses more observations than necessary to solve the navigation equation (over determination)
- The receiver has some expectations about the accuracy of each observation (usually expressed by standard deviation)
- RAIM: how well does over determination fit the expectations?
- Bad observations can be rejected from the solution (if you are lucky)

RAIM concerns

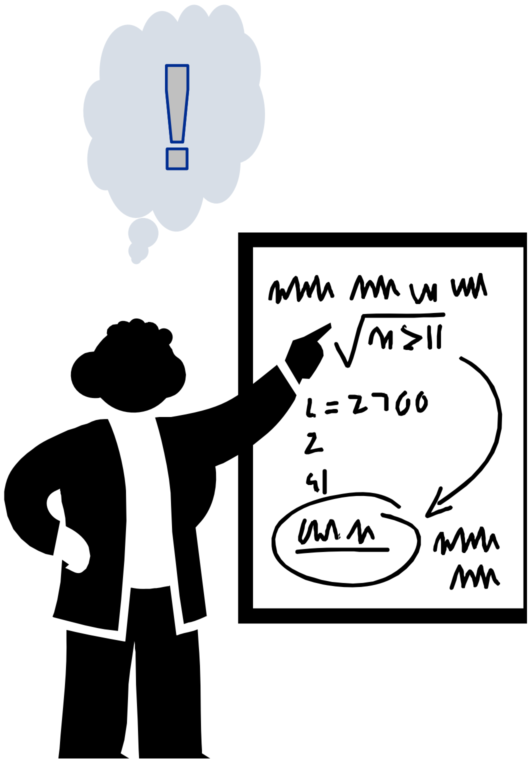
- RAIM helps a lot but:
  - You need to do it right
  - Does not solve everything

- RAIM modes:
  - GPS
  - GPS + Glonass
  - Multiple DGPS processing
  - Relative GPS
  - GPS & INS aiding

- A lot of things can ruin integrity

THEORY VS. REAL LIFE

Integrity in Scientific or Operational Domain?



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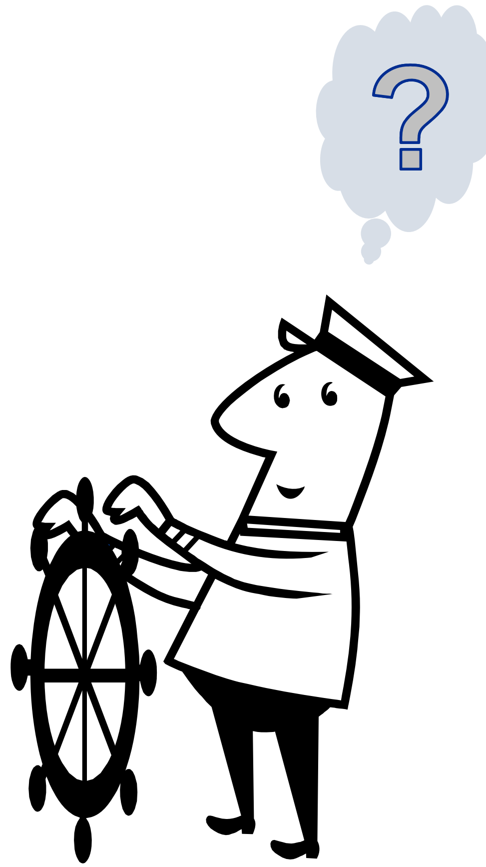


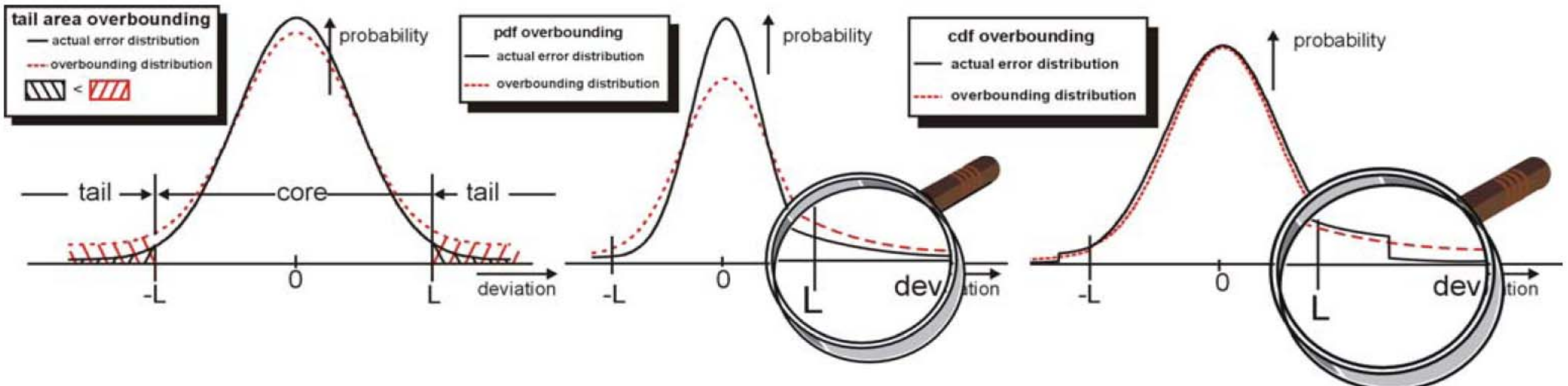
Integrity Improvement Strategies

Theoretical approach

- Find an overbounding error distribution
- A pessimistic standard deviation does not work well for RAIM

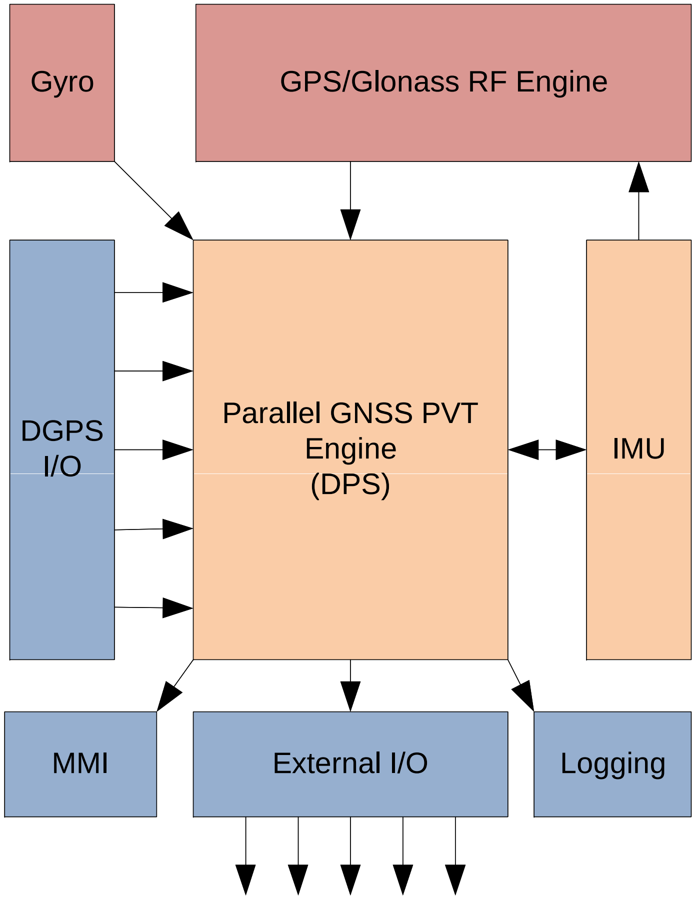
Real life approach

- Study unexpected events
- Endured learning
- Using a GNSS simulator
- Replay tons of data

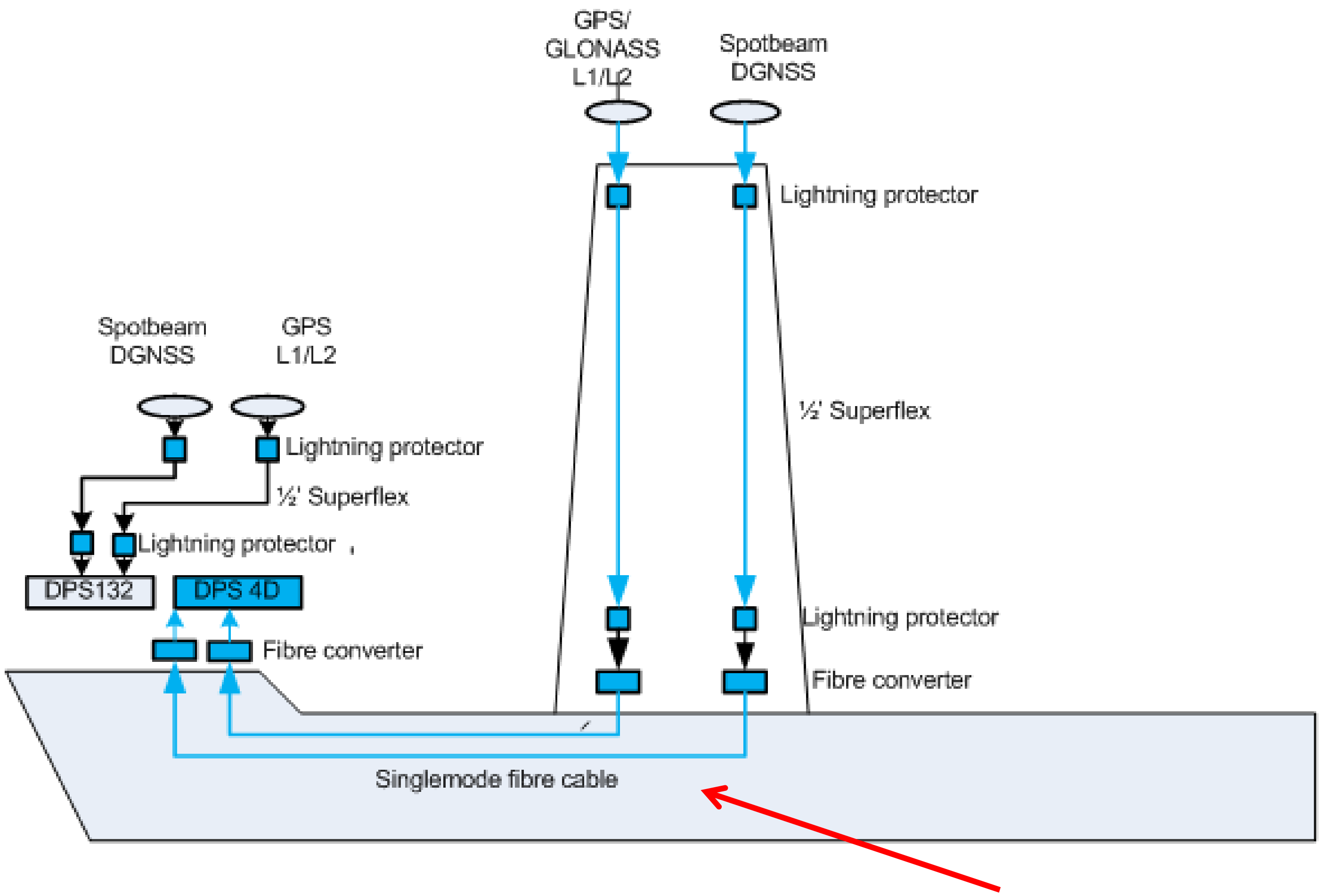


Ref: Pieter Bastian Ober

Complexity of a GNSS engine



Complexity if an installation

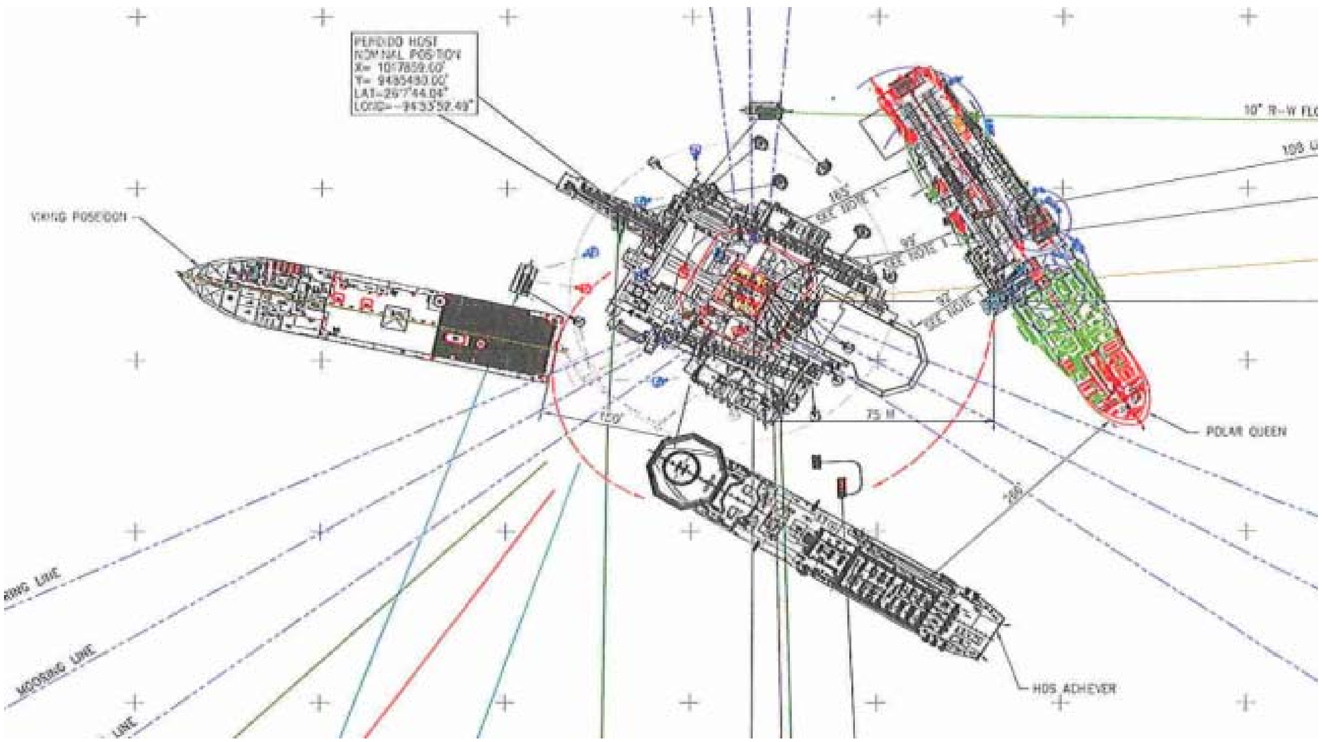


CG – Centre of Gravity

Error Propagation and Lever Arms

		Lever arm (m)				
		10	30	100	300	
Angle error (degrees)	0,01	0,00	0,01	0,02	0,05	(MRU 5+)
	0,02	0,00	0,01	0,03	0,10	(MRU 5)
	0,05	0,01	0,03	0,09	0,26	(MRU H)
	0,15	0,03	0,08	0,26	0,79	(MRU Z)
	0,35	0,06	0,18	0,61	1,83	(MRU D)
	1	0,17	0,52	1,75	5,24	
	3	0,52	1,57	5,24	15,72	

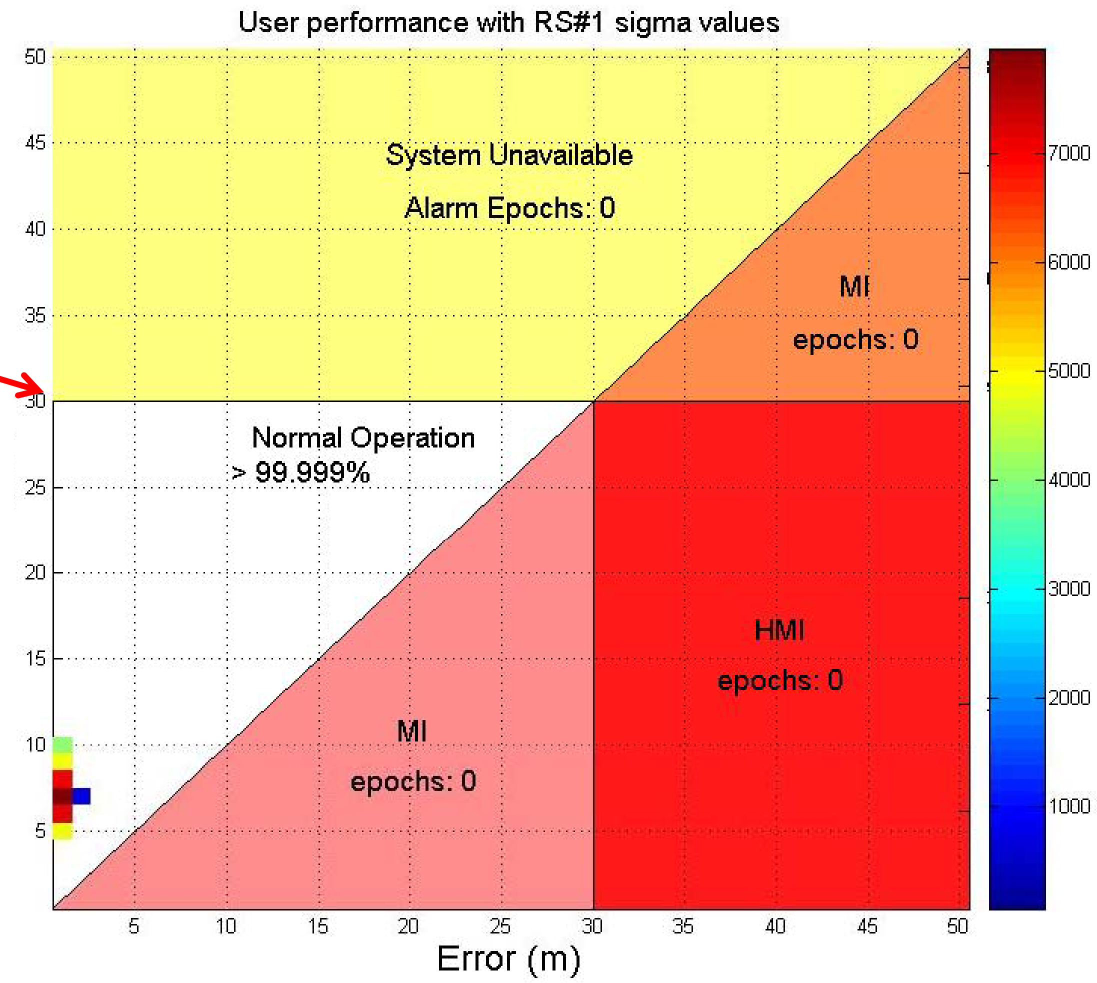
Complexity of a SIMOPS operation



ACCURACY VS. INTEGRITY

Integrity by Stanford Plots

Alarm Limit

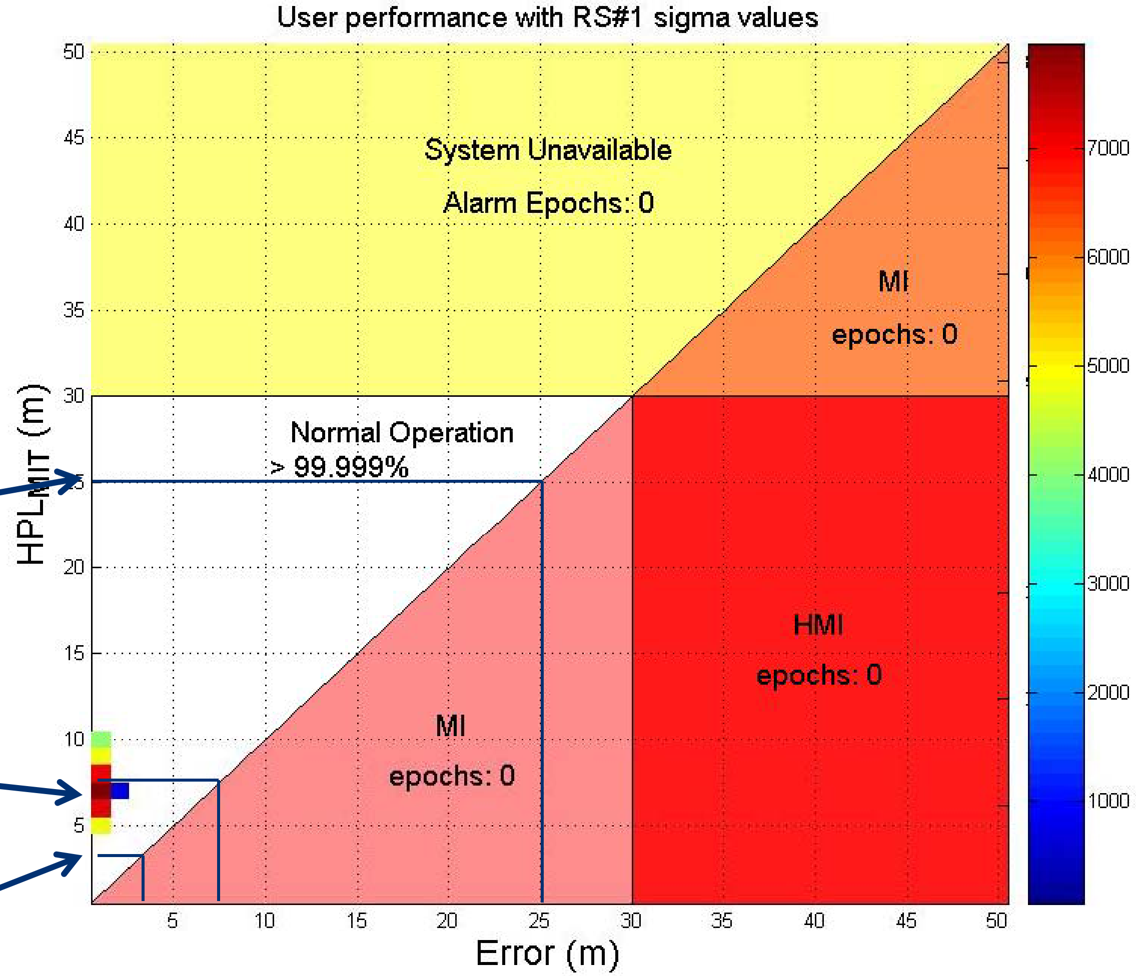


What Should the Alarm Limit Be?

IMO A.953(23) GNSS antenna 25m

DP Centre-of-Gravity 7,5 m?

SIMOPS Hull-to-hull 2,5 m?



(*) HPL is typically 2.5 x accuracy

CONCLUSION

Operational GNSS integrity

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- Integrity is probably the most important quality difference between a low-cost GPS receiver and a professional solution
- Operational GNSS integrity comprises a lot more than just GNSS signal-in-space
- Operational GNSS integrity need to include a lot of factors outside the GNSS receiver
- Other DP reference systems should also focus in integrity