GRAD Driving Innovation for Safer Maritime Navigation

Balancing integrity with continuity of maritime navigation in a multi-system receiver and the need for future, realistic maritime performance requirements

Dr Paul Williams, Mr Chris Hargreaves, Mr George Shaw, Dr Jan Safar,
Dr Alan Grant and Mr Martin Bransby

RIN INC, November 2019

© GLA Research & Development Directorate, The Quay, Harwich, CO12 3JW

Introduction

- The maritime sector is evolving with new technology and data services to support the mariner.
- The IMO e-Navigation concept should support new data services, all underpinned by safe and reliable positioning and navigation data.
- Autonomous vessels have the potential to be a game changer.
- All developments need to balance the differing user requirements depending on the operation at hand.

Image source: www.digitaltrends.com & Rolls-Royce

Maritime requirements - today

- IMO Resolutions A.1046 and A.915 are used today, although not ideal.
- There is a need to develop a document that sets out today's maritime requirements.
- Guidelines developed in support of the IMO's Multi-System Receiver performance standard provide a framework for extending performance requirements but more work is required.

INTERNATIONAL MARITIME ORGANIZATION

Image source: IMO

IMO Resolution A.1046

Worldwide radionavigation system – December 2011

- This Resolution details the requirements for a radionavigation service that is being offered as part of the IMO's WWRNS.
- Systems approved as part of the WWRNS are deemed suitable for navigation on SOLAS vessels.

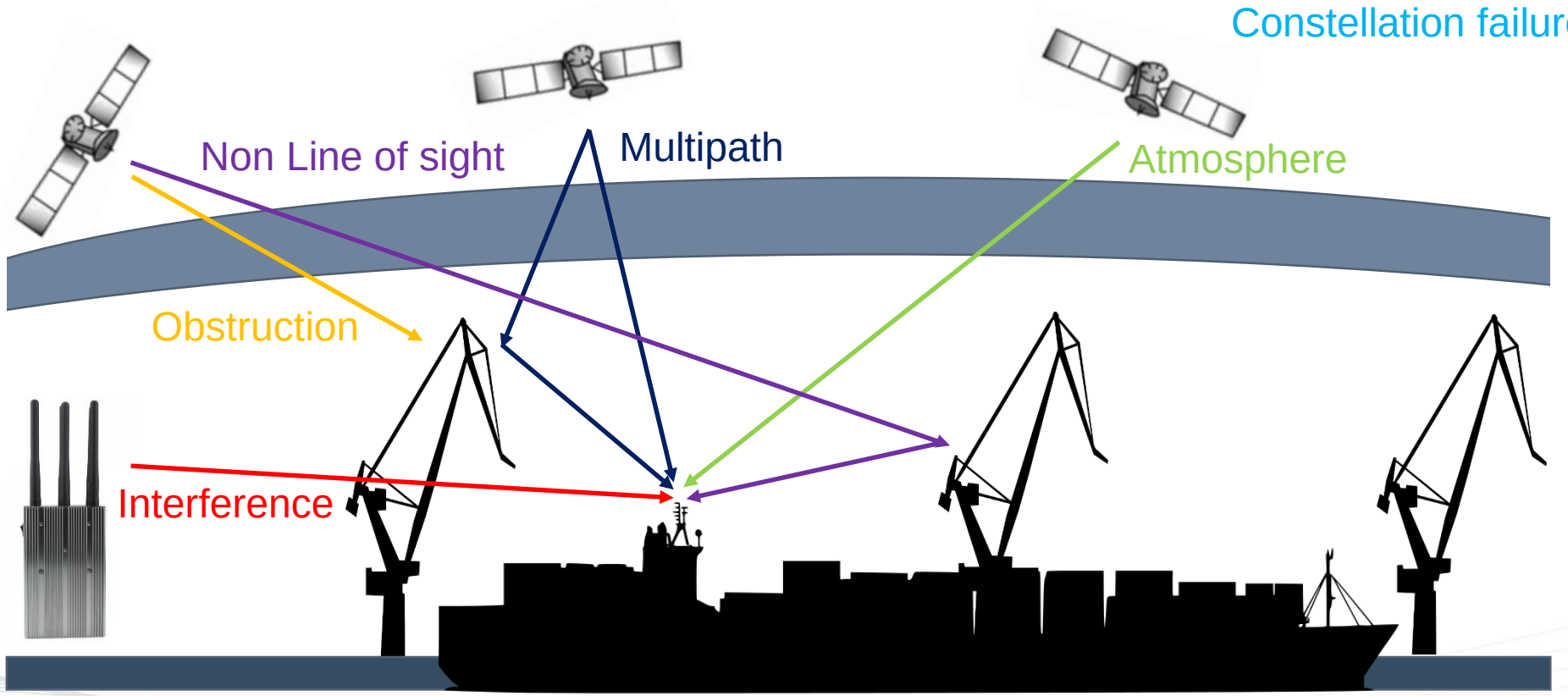
Voyage Phase	Accuracy	Continuity	Integrity (TTA)	Availability	Update Interval
Ocean Water	100m (95%)	N/A	As soon as possible	99.8% (signal)	2 s
Harbour Entrances, Approaches and Coastal Waters	10m (95%)	≥99.97% (15 mins)	10s	99.8% (signal)	2s

"The system shall be considered available when it provides the required integrity for the given accuracy level."

System level integrity

Source: IMO Resolution A.1046

System and user level integrity



System level integrity – considers failures external to the vessel.
User level integrity – considers system level components, plus the local environment and receiver.

Jammer image from: https://www.jammer-store.com

IMO Resolution A.915

Revised maritime policy and requirements for a future Global Navigation Satellite System (GNSS) – January 2002

- Looking at future requirements (when written) expected to be achieved in 2010, and notes the need for revision in the future.
- Recognises the need for augmentation to support integrity requirements.
- Aging document (almost 18 years old) – some bits out of date.

	System level parameters				Service level parameters			
	Accuracy (95%)	Integrity			Availability (% per 30 days)	Continuity (% over 3 hours)	Coverage	Fix interval (s)
		Alert limit (m)	Time to alarm (s)	Integrity risk (per 3 hrs)				
Ocean	10	25	10	10^{-5}	99.8	N/A	Global	1
Coastal	10	25	10	10^{-5}	99.8	N/A	Global	1
Port approach and restricted waters	10	25	10	10^{-5}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1

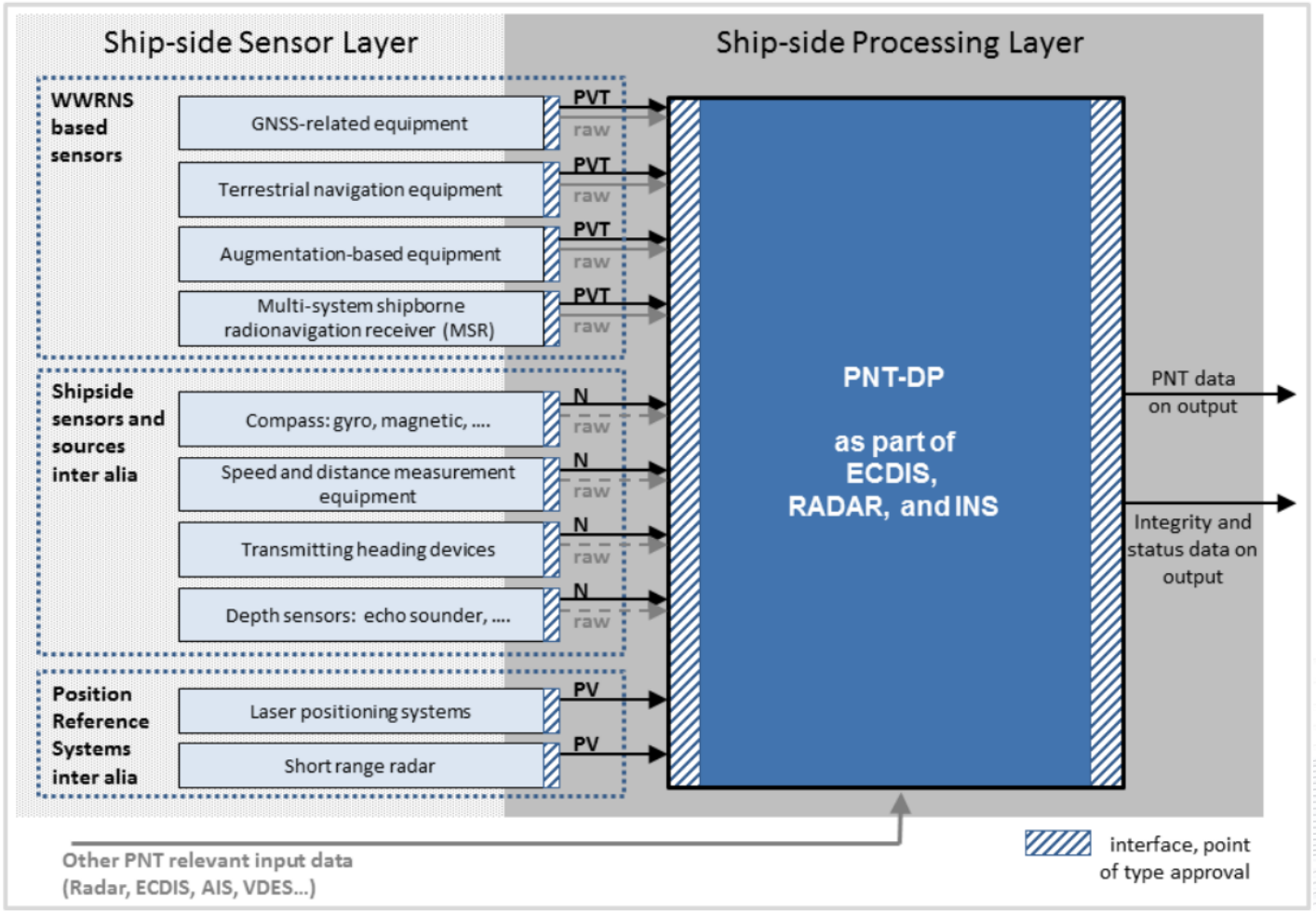
Source: IMO Resolution A.915

IMO Multi-System receiver & Guidelines

Multi-system receiver performance standard is designed to allow integration in the receiver or elsewhere, to enable scalability.

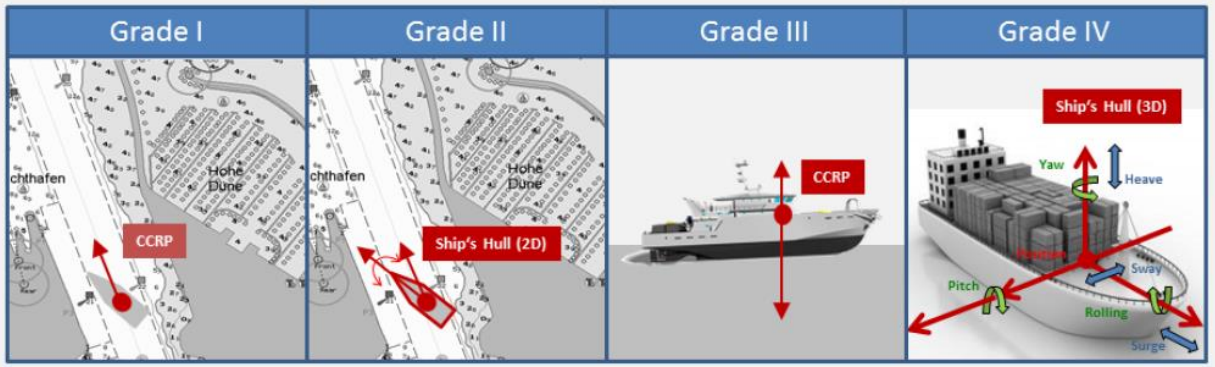
The design allows various inputs into the PNT data processor.

It also allows RAIM and the concept of multi-system RAIM to be used for integrity.



Source: IMO MSC.1-Circ.1575

IMO Multi-System receiver & Guideline



PVT data:
- Latitude and Longitude
- SOG and COG
- Time

Horizontal PNT data:
PVT data +
- Heading and ROT
- STW and CTW

Extended PNT data:
Horizontal PNT data +
- Altitude
- Depth

Full PNT data:
Extended PNT data +
- Heave, sway*, and surge*
- Yaw*, pitch, and roll

The MSR Guideline proposes a means of scaling the requirements based on the operation.

The Guideline provides indicative operational requirements for various inputs.

It also recognises that integrity requirements increase as the number of inputs increase.

PNT Output Data	Operational Accuracy Level				Level of Confidence[8] [%]
	A	B	C	D	
Horizontal Position [m]	100.0[9]	10.0[9,10]	1.0[10]	0.1[10]	95
SOG [kn]	0.5	0.4	0.3	0.2[11]	95
COG [°]	3.0	1.0	0.5	0.1	95
Time[12]	1.0 s	0.1 s	0.0001 s	50.0 ns[13]	95
Heading [°]	1.5[14]	1.0[14,15]	0.5[14]	0.2[14]	95
ROT [°/s]	1.0	0.5[16]	0.3	0.1	95
STW [kn]	0.5	0.4	0.3	0.2[11]	95
CTW [°]	3.0	1.0	0.5	0.1	95
Vertical Position [m]	10.0	5.0	1.0[10]	0.5	95
Depth [m]	5.0	1.0	0.5	0.2	95
Pitch [°]	1.5	1.0	0.5	0.2	95
Roll [°]	1.5	1.0[15]	0.5	0.2	95

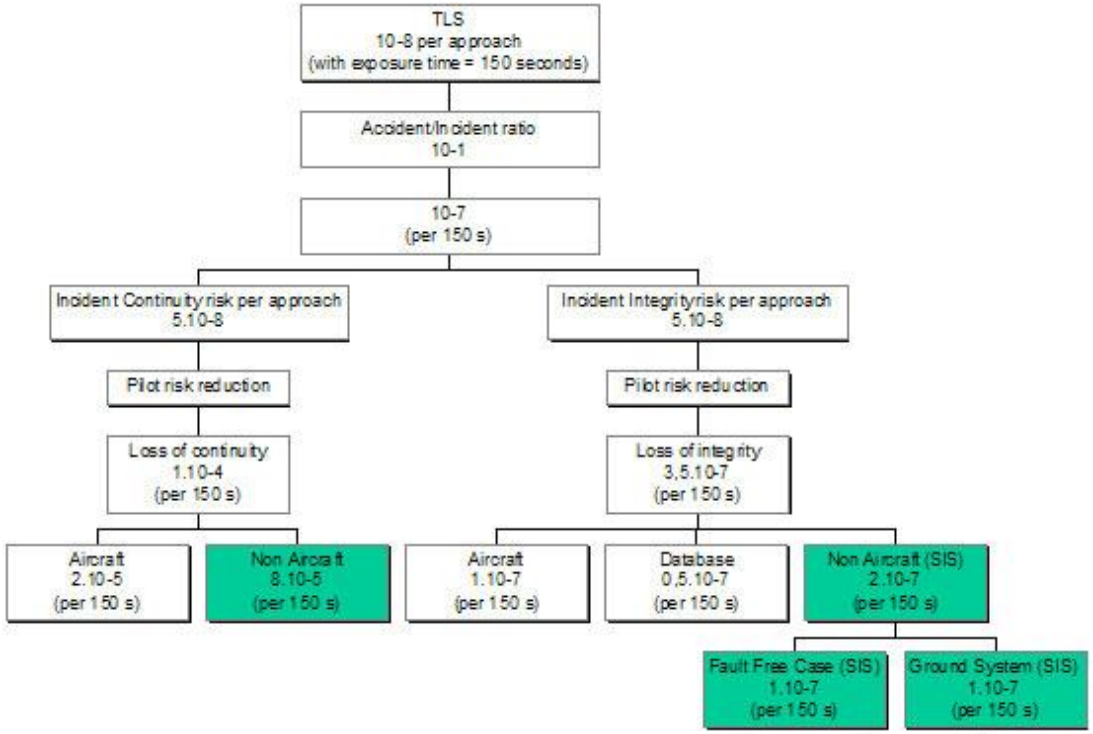
Source: IMO MSC.1-Circ.1575

Resilience as a requirement

- It’s widely recognised that maritime PNT data should be resilient, but how much resilience is enough?
- IALA provides guidance in Recommendation R-129, giving options of redundant, backup and contingency solutions.
- The amount of resilience may change depending on the operation, location, time, environment etc.
- How should resilience be captured in today’s maritime requirements?
- What backup system(s) meet the resilience requirement?

Fault Tree Analysis – aviation example

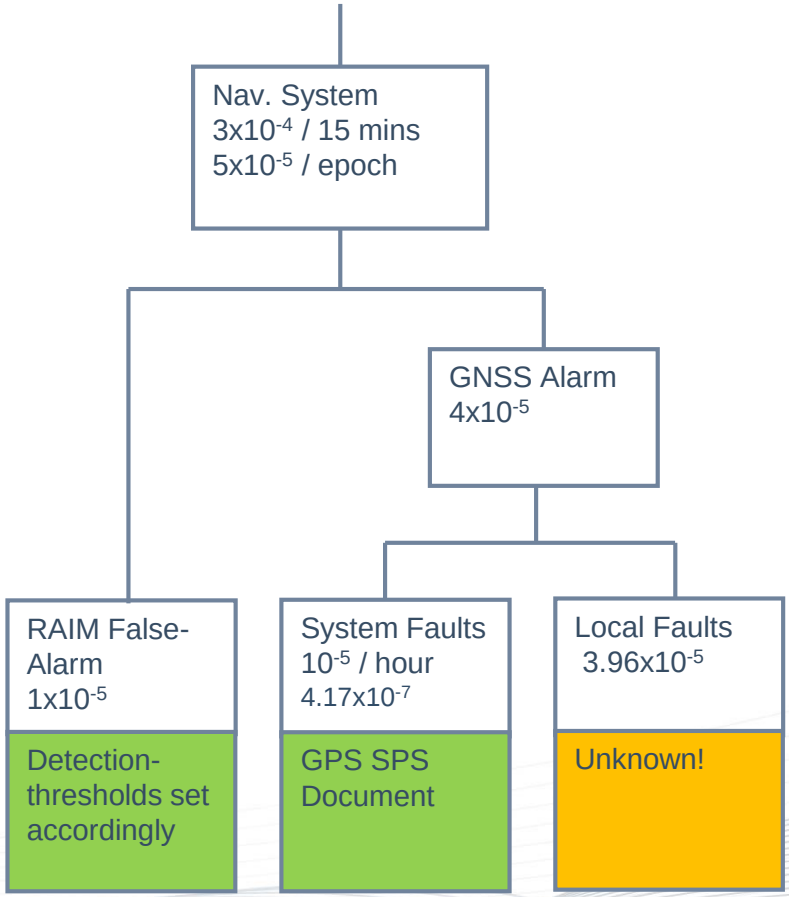
- Consider all risks
  - Vessel
  - Equipment
  - Receiver algorithms
- Risk break-down
  - Each component must meet its requirement
- Top-Level Requirement
  - Target Level of Safety (TLS)
  - Example is SBAS for aviation
  - We do not have a Maritime equivalent!



Source: ICAO

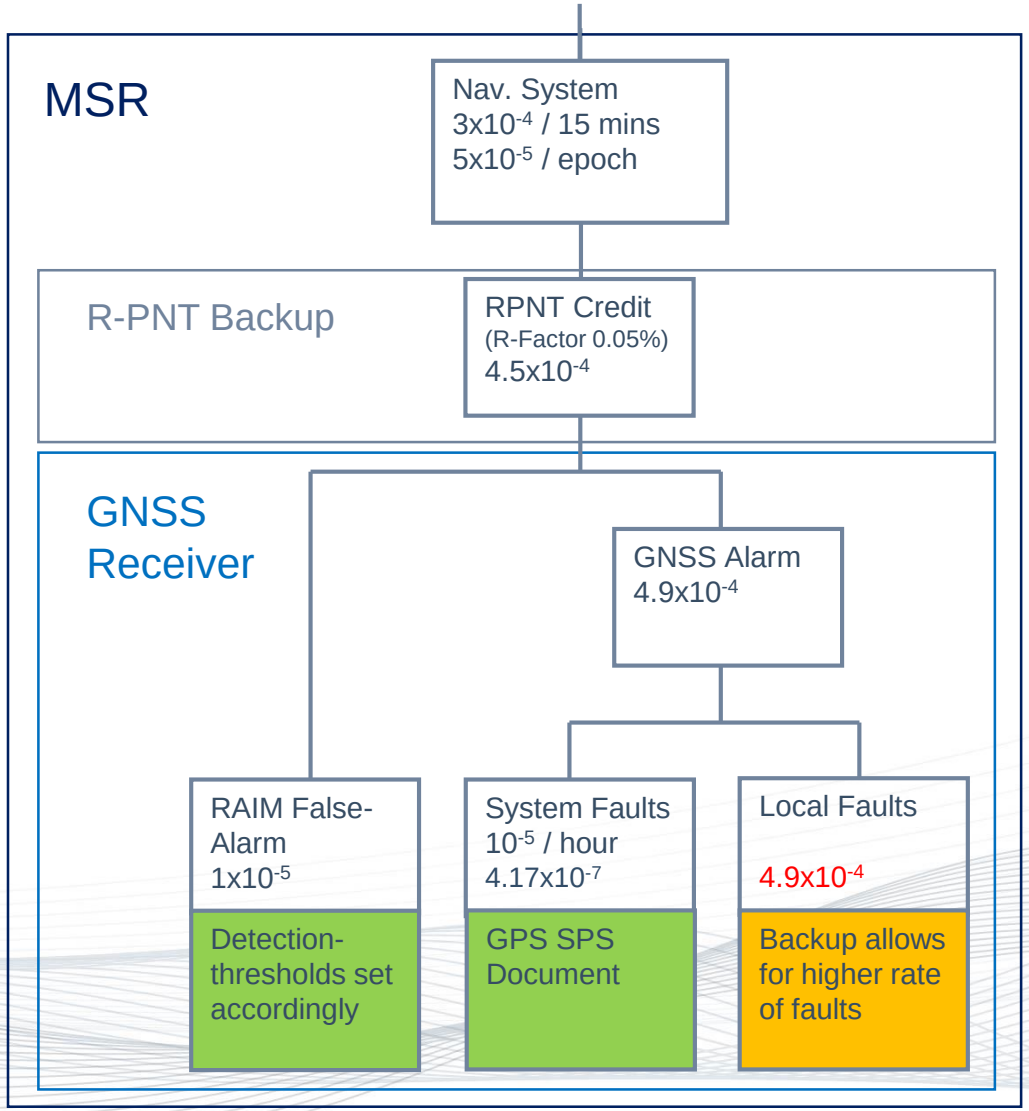
Continuity Fault Tree

- Budget $5x10^{-5}$ per epoch
  - Equipment failures (small)
  - RAIM False-Alarms (10^{-5})
  - GNSS Faults ($4x10^{-5}$):
- Rate of GNSS Alarms is unknown
  - Depends on severity of noise / multipath in marine environment
  - System-level faults are rare and well-defined
  - We can only control false-alarm rates
  - Will need an extensive measurement campaign to determine risks!



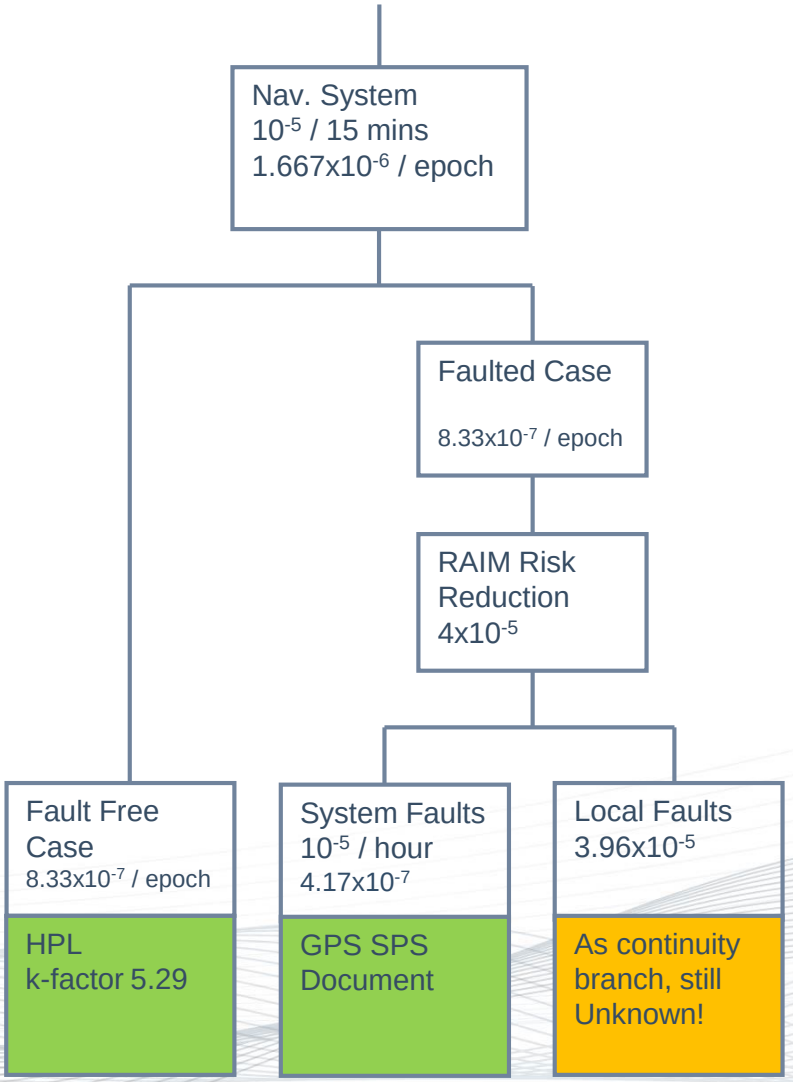
Continuity Fault Tree (MSR)

- MSR consists of the GNSS receiver and an independent backup.
- On condition of a continuity breach on the GNSS receiver the backup system is automatically engaged.
- Provision of the backup offers a continuity credit.
- Backup solution doesn't need to be as good as the primary to provide a benefit.



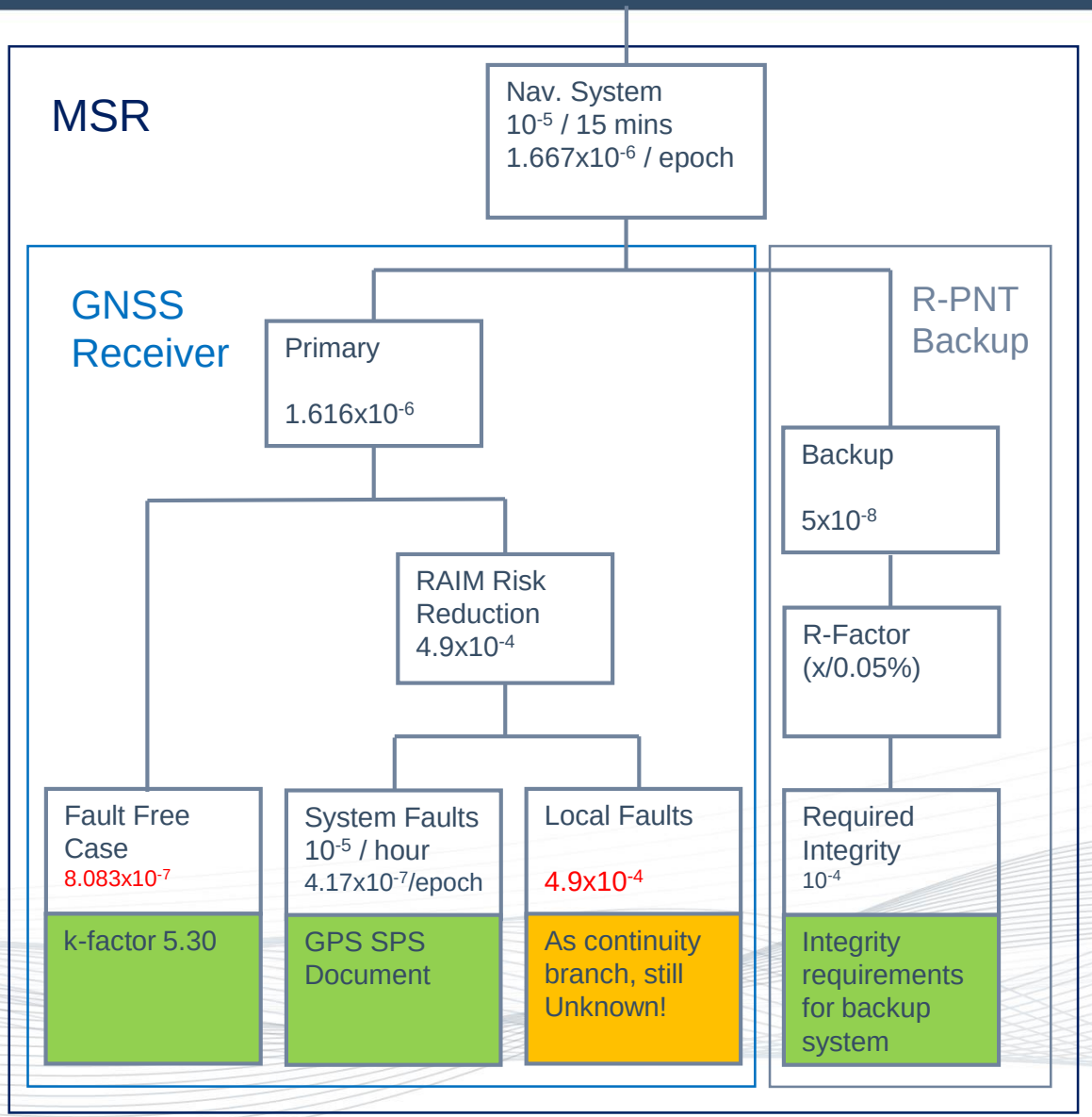
Integrity Fault Tree

- Top-level budget 1.667×10^{-6} per epoch
  - 50% to fault-free case (8.33×10^{-7})
  - 50% to faulted case (8.33×10^{-7})
- Fault-Free Operation
  - Fault-free case is the chance of the system not detecting an error – Probability of missed detection.
- Faulted Case
  - True GNSS Faults
    - System-level (can be mitigated by augmentation – not shown)
    - Local faults: (unknown probability!)
- RAIM requirement depends on local environment
  - Need a measurement campaign!



Integrity Fault Tree (MSR)

- Apportion small amount of budget to the backup
  - $5x10^{-8}$ for backup
  - Majority for primary (GNSS)
- Integrity risk weighted by duty-cycle (up-time)
  - Backup in use 0.05% of time
  - Primary in use 99.95%
  - Can afford lower performance from backup system
- HAL remains at 25m
  - Same accuracy required from backup (~10m, 95%)



Known Issues

- Unsure of Continuity performance
  - Rate of local faults in GNSS unknown
  - Might exceed continuity budget
- Unsure of Integrity Performance
  - FD / RAIM design depends on severity of threats
  - Depends on frequency of local faults
    - V. Rare = No RAIM needed
    - Rare = Simple RAIM algorithm
    - Common = Complex RAIM algorithm
- Long-term study required
  - Severity of local-interference to the vessel
  - Ability to conservatively bound multipath errors
    - Vessel multipath estimate akin to aviation SBAS model
    - Better standardisation of antenna installations?
  - Need a RAIM algorithm tailored to the marine environment
  - Integration with backup system can improve continuity

Conclusions

- There is a need to define today's maritime requirements, including resilience.
- A method of quantifying what resilience means to the overall continuity and integrity risk budgets has been introduced.
- This approach can help derive the requirements for resilience moving a step forward to linking operational requirements to candidate resilient PNT systems.
- We've seen that continuity and integrity requirements are linked and need to be balanced.
- Significant data is needed to model and quantify the local error sources (noise and multipath etc) effects across different vessels, location, seasons etc.

Thank you

Contact Information

Dr Alan Grant

Email: alan.grant@gla-rad.org, Phone: +44 (0)1255 245141