



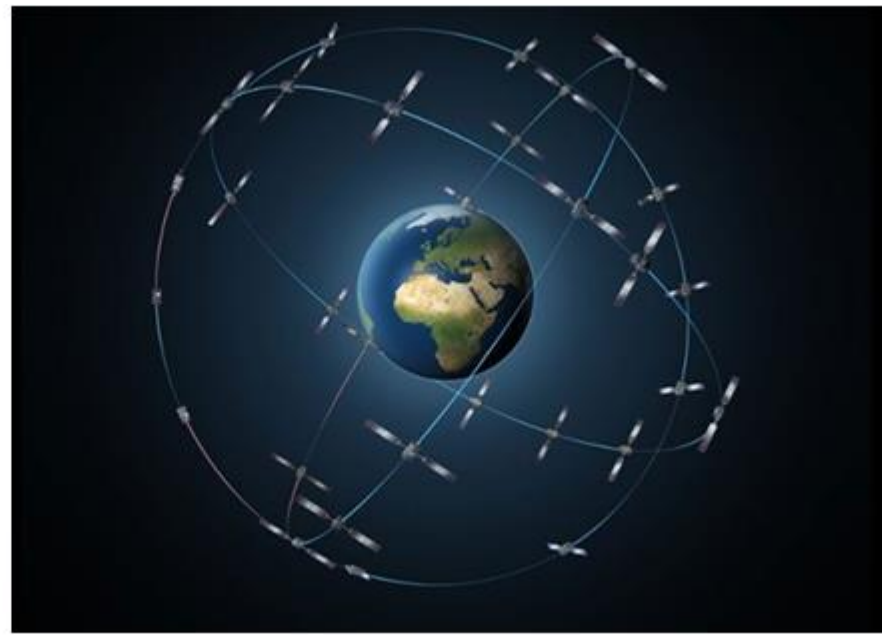
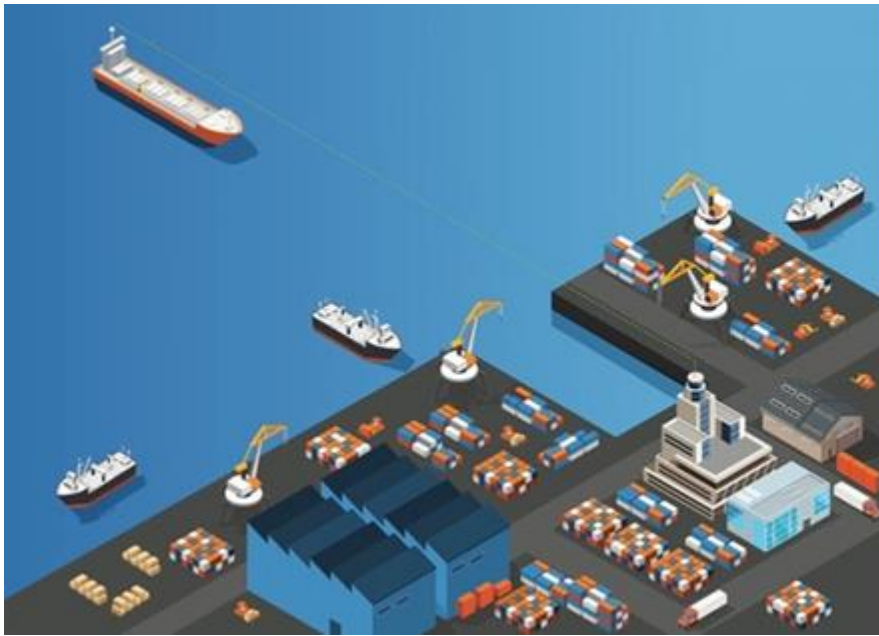
NAVISP Industry Days
Element 3 – Support to Member States
23 January 2020

Title and main objectives



Maritime Resilience and Integrity of Navigation

Building resilience & integrity into UK critical national infrastructure for maritime navigation, aids to navigation infrastructure and services at sea and in ports



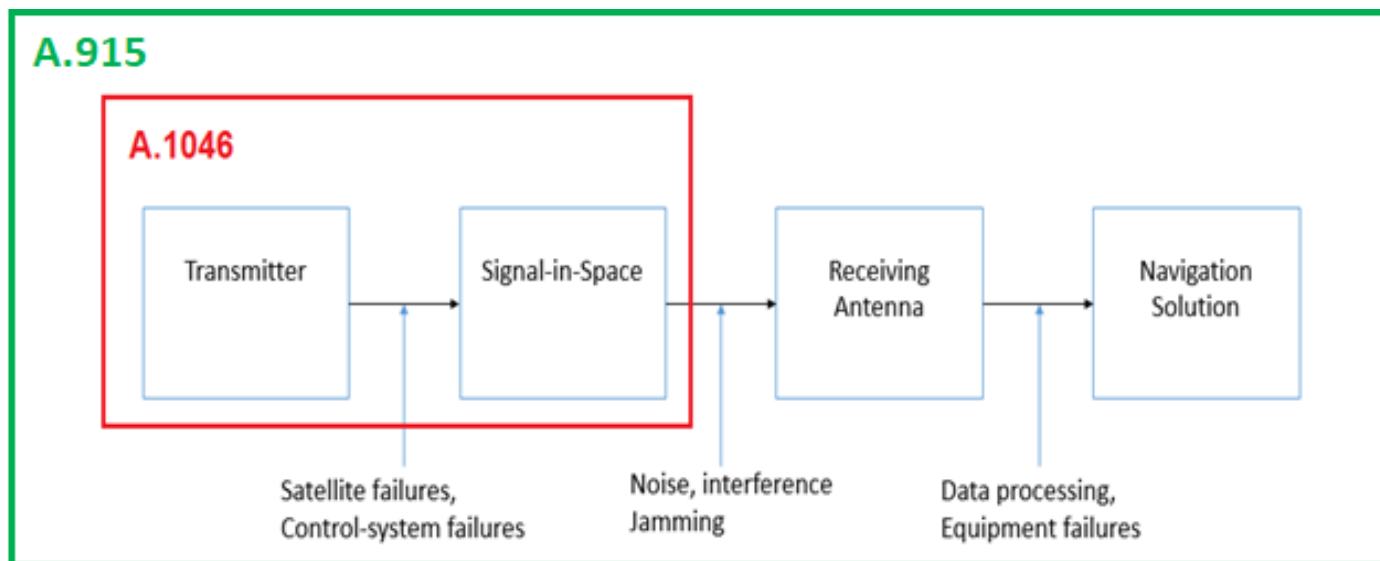
By 2032 ensure the resilience and integrity of the UK critical national infrastructure relating to maritime and port PNT and communications are underpinned with an appropriate network of systems taking account of international practice

Integrity

The ability to provide users with warnings within a specified time when the system should not be used for navigation which makes the position solution robust to any arbitrary fault, or disruption, likely to occur in the real world, e.g. cyber threat, space weather, deliberate jamming



Diagram source: J. O. Klepsvik, P. B. Ober, and M. Baldauf, 'A Critical Look at the IMO Requirements for GNSS', ION GNSS 20th International Technical Meeting of the Satellite Division, Sep. 2007.



Resilience

The ability to anticipate, mitigate and recover from disruption.

From a maritime perspective the activities of **resilience** includes:

1. The provision of a ***user-level integrity*** guarantee, which makes a GNSS-derived position solution robust to any arbitrary fault, or disruption, likely to occur in the real world, e.g. cyber threat, space weather, deliberate jamming
2. The provision of sufficient hold-over capability from ***alternative systems*** and sensors that the ***continuity*** guarantee is not undermined by loss of GNSS, for example due to an integrity-alert, jamming or interference

The mariner just wants to *get on with his job...safely* and **efficiently** while **protecting the marine environment!**

Principle of Resilient PNT:

*Using **integrity** monitoring to effect a seamless handover to an alternative **available** system that provides sufficient **accuracy** with **integrity**, to ensure the **continuity** of the mariner's operation!*

Encompasses ALL RNP parameters!

Consortium



Team members



Project participants	Role
NLAI Ltd	Prime, user need coordination
General Lighthouse Authorities	Technical lead, performance analysis
KTN	User & stakeholder engagement
London Economics	CBA
University of Nottingham	PNT- EGNOS and integrity
UCL	PNT - hybrid solutions & resilience
Terrafix	Architectural concept
Taylor Airey	CNI, PNT & consultant
BMT	Port and pilot analysis

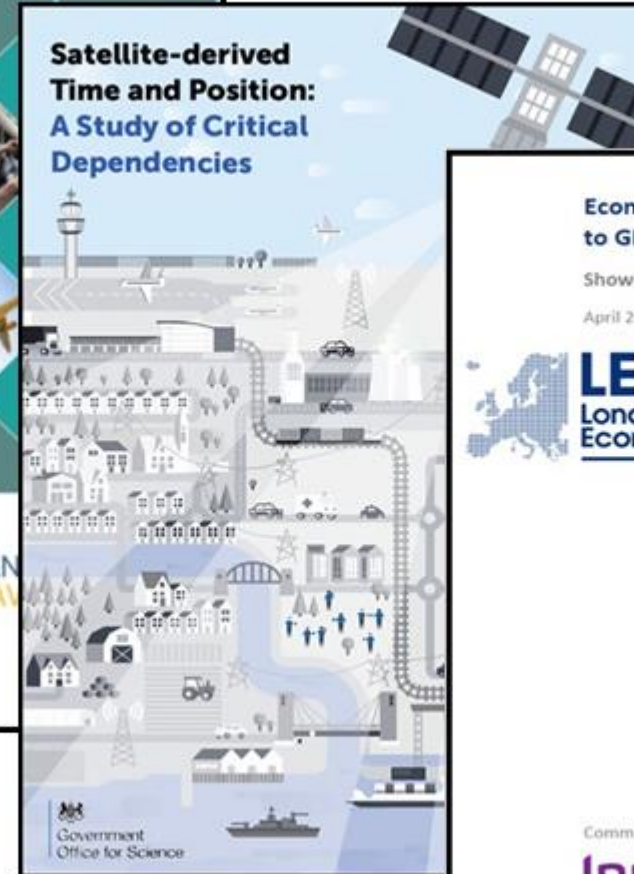


National strategy addressed & expected outcome



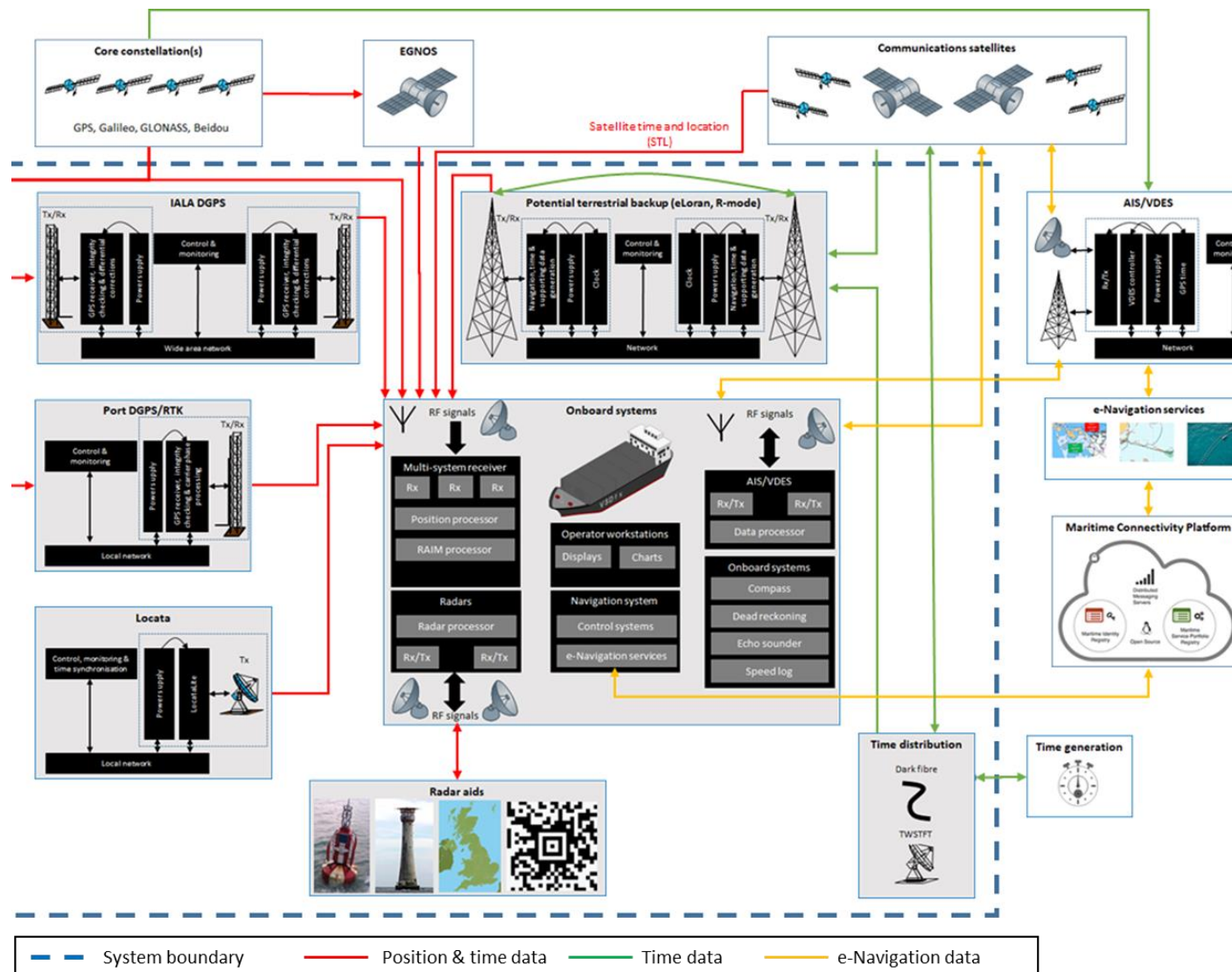
The need for MarRINav

- **ERNP**
 - ...GNSS signal vulnerabilities need to be addressed...
 - ...robust and resilient PNT information ... requires a core GNSS, an augmentation system and adequate backup....
- **Blackett Report**
 - ...dependency on GNSS....
 - ...recommends measures to improve resilience....
- **London Economics report**
 - ...economic impact to the UK of a five day disruption of GNSS is estimated at **£5.2bn**...
 - ...maritime sector's share of this impact is 21% of the total (~**£1.1bn**)...



Conceptual architecture

- **GNSS at the core**
 - Multiple constellations
 - EGNOS
 - RAIM
- **Multi-system, multi-constellation receiver**
- **Redundant, contingency or back-up systems**
 - eLoran
 - VDES R-mode
 - STL
 - Locata
 - Radar positioning
 - Onboard systems
- **Time dissemination independent of GNSS**
 - TWSFT
 - Dark fibre
 - TWLFTT
- **System-of-systems approach**

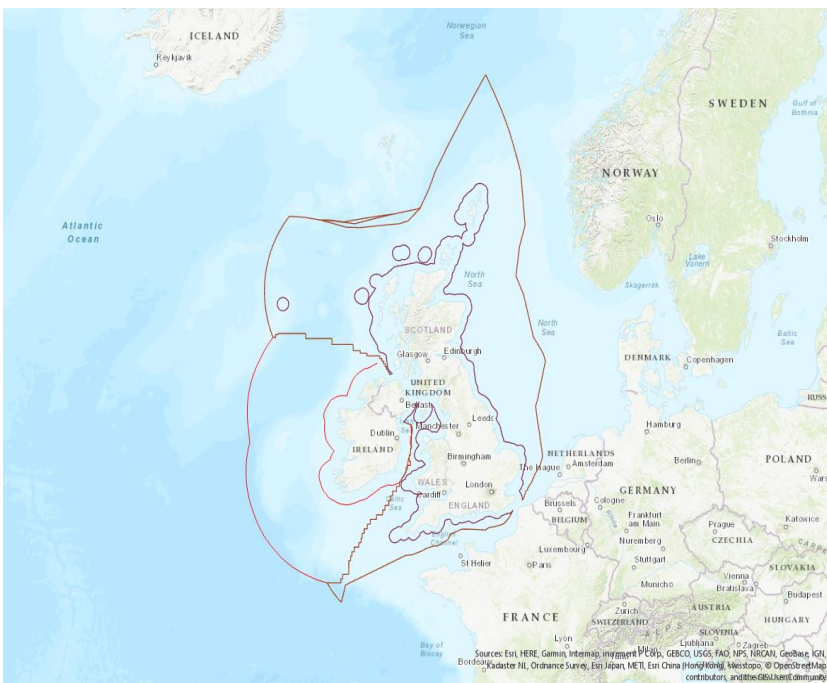


Scope



Geography

- EEZs of UK and Ireland: all major ports and traffic separation schemes
- Areas of higher collision risk: traffic density & complexity; offshore infrastructure
- Blue Economy areas and environmentally sensitive areas



Applications

- All voyage phases for marine navigation: ocean, coastal, harbour approach, port
- Port operations
- Access to hinterland

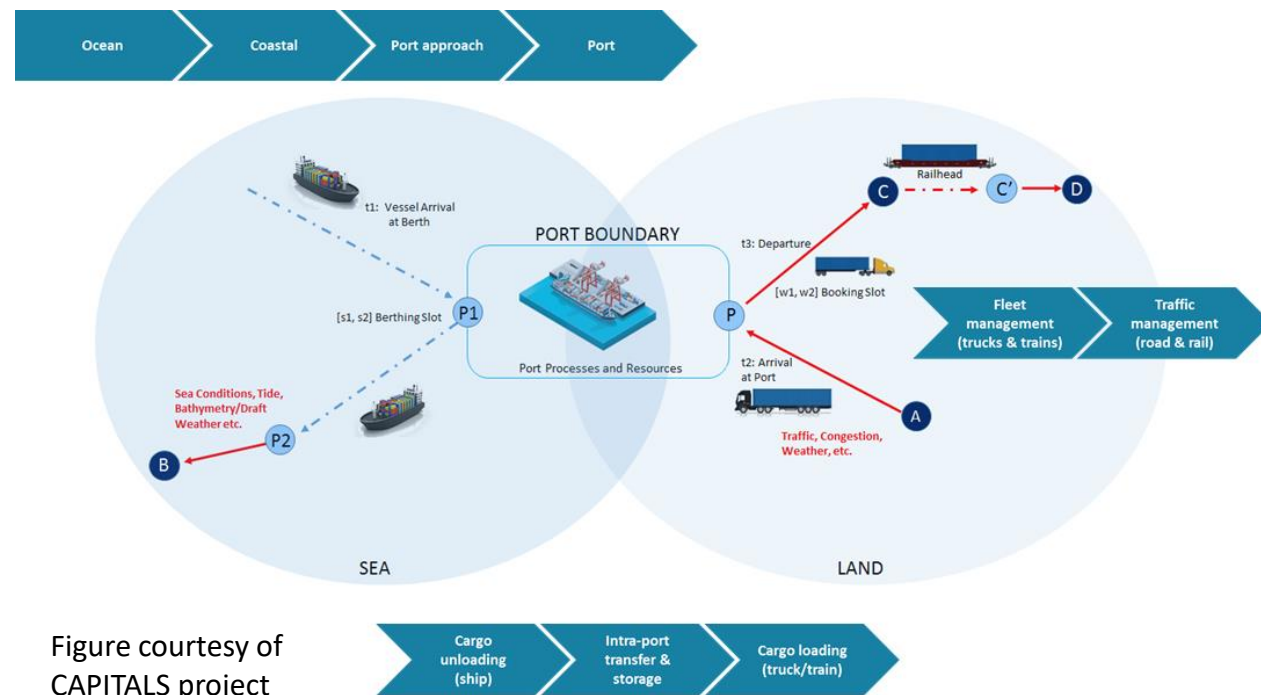
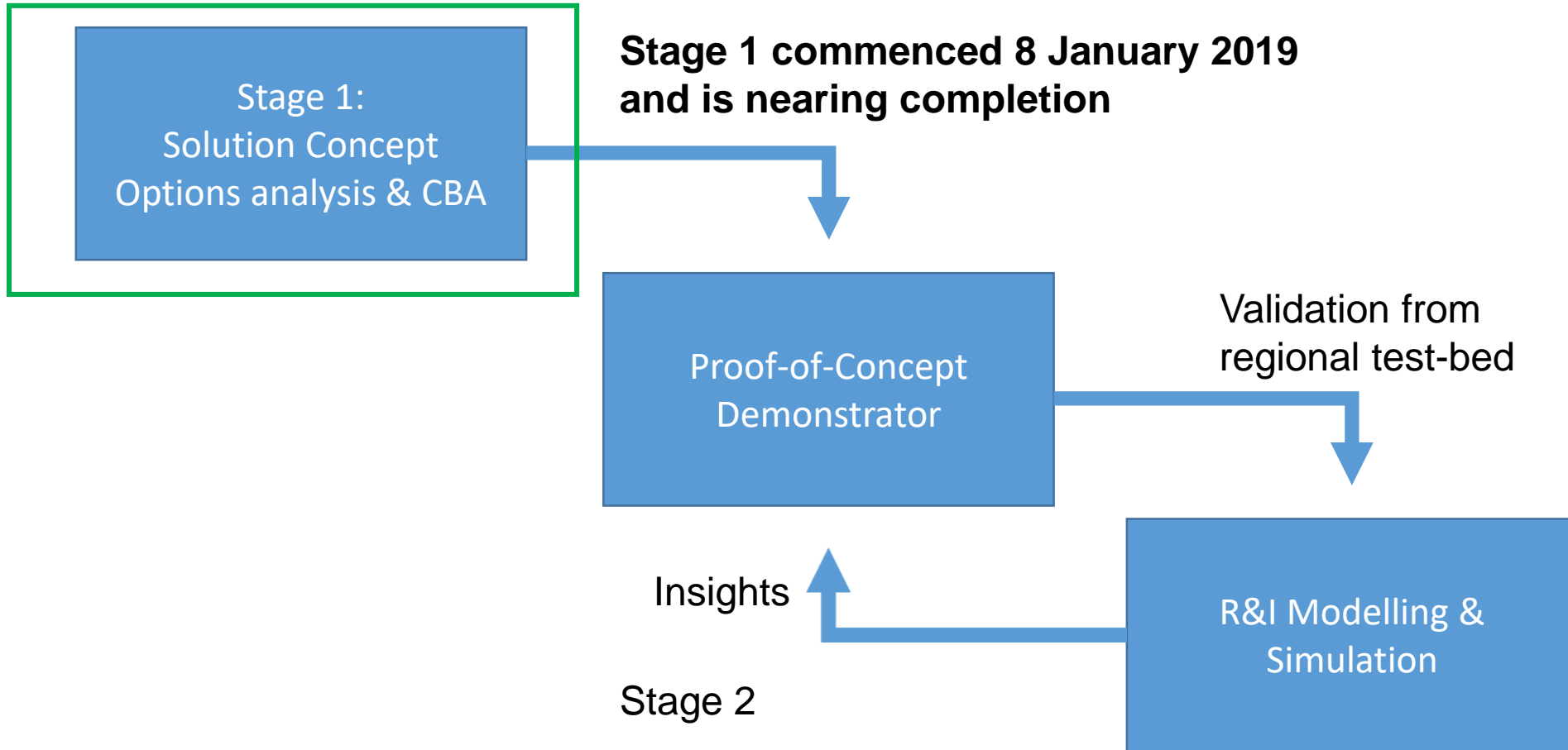


Figure courtesy of CAPITALS project

Activities



Three year duration (1 year Stage 1 – possible Stage 2 over 2 years)



Results - resilience



Resilience assessment for components of the system-of-systems

Systems included in exploration of the UK RPNT architecture

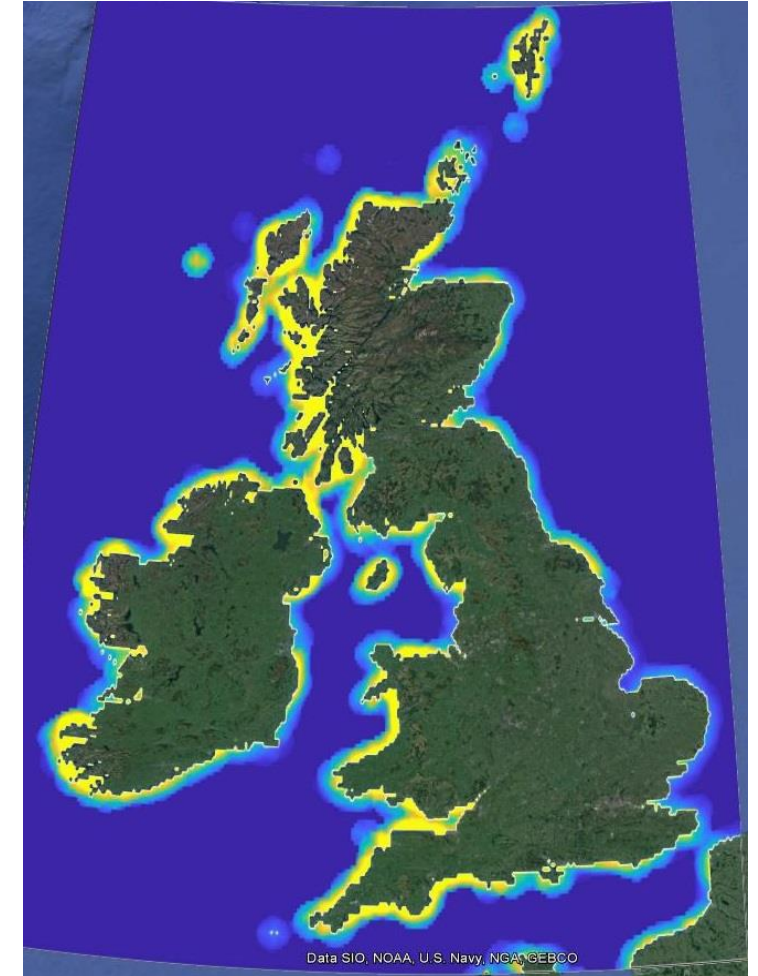
- eLoran
- VDES/AIS R-Mode
- Radar absolute positioning (Radar SLAM, or RaDR)
- Onboard systems

In addition the following will be assumed:

- LOCATA – for ports – Very local - operational
- STL (Satelles) – for Ocean Voyage Phase – global

MF R-Mode is not considered as part of the UK RPNT architecture, but it is included in WP3 should technical difficulties be solved

GNSS – core constellations and EGNOS – remain at the core of the architecture



Emerging conclusions

UK eLoran based on the Anthorn transmitter with additional stations located at current TV transmitters gives good positioning performance (nine of 10 major ports) but with some gaps in critical locations

UK eLoran based on Anthorn alone with appropriate augmentation provides a high accuracy UK-wide timing source

VDES R-mode alone based on current UK AIS infrastructure alone does not give benefits

UK eLoran with the mothballed station at Sylt in Germany enhances coverage but still does not deliver the required performance around the Dover Strait

VDES R-mode with additional local stations in the UK and France fills most of the coverage gap in the Dover Strait with improved coverage if eLoran and VDES R-mode are integrated

Radar absolute positioning has the potential to meet accuracy requirements close to the coast but not at all critical locations

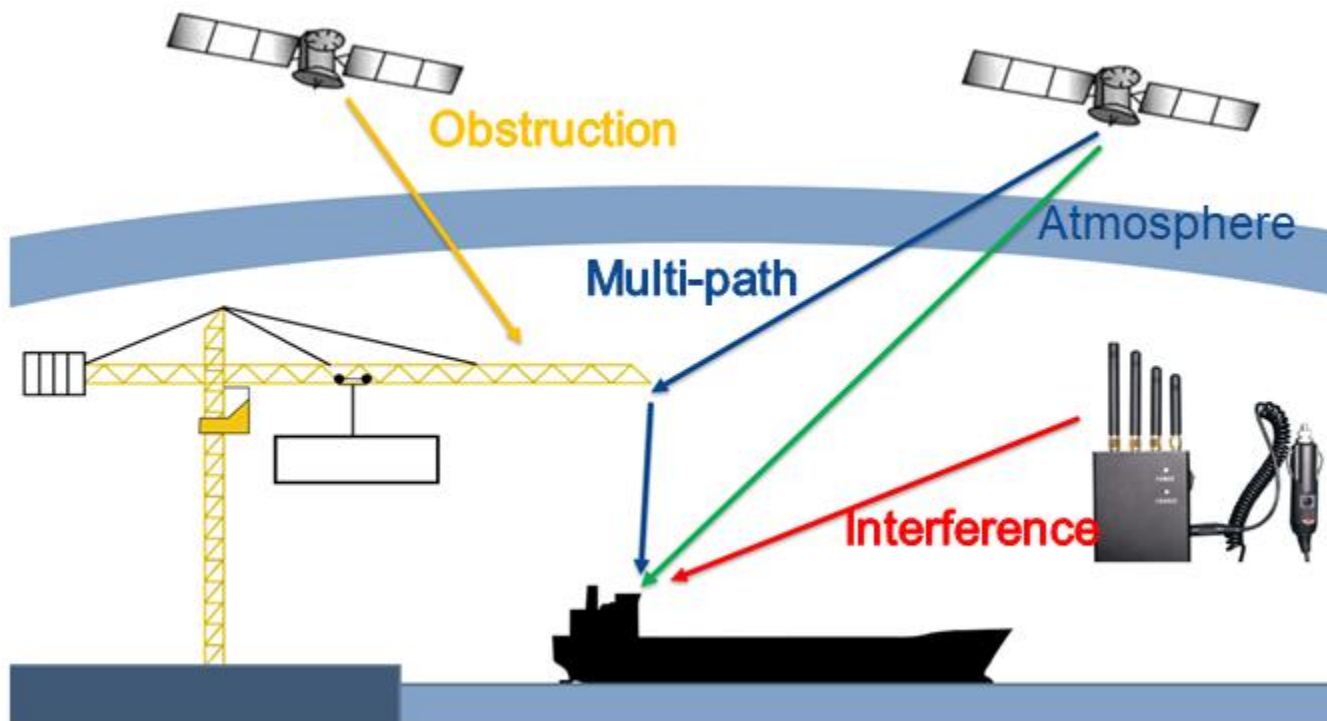
A PNT solution of UK eLoran/VDES with addition of 3 VDES stations in France and Sylt eLoran in Germany would achieve resilience for the whole of UK and Ireland EEZs, entire Dover Straits and Channel approaches'

A UK-only fully resilient PNT solution covering all critical areas cannot be achieved

Results - integrity



Integrity at user level in the complex maritime environment



Integrity threats - several simultaneous faults possible

- Satellites (orbit, clock) and atmosphere (ionosphere)
- Local hazards (noise, multi-path....)

Integrity warning given to User

Availability (user level)

- Green light is on

Continuity (user level)

- Green light stays on for guaranteed length of time

Must preserve Integrity

Missed detection: light is green, should be red
Need to control probability of missed-detection (p_{MD})

Must preserve Continuity

False alarms: light is red, should be green
Need to control probability of false-alarm (p_{FA})

Define “Misleading Information” (MI):

- Error exceeds Alert Limit without Red light warning
- **Integrity (user level)** = probability of HMI



EGNOS and M-RAIM provides potential user level integrity solution...

EGNOS V3 (or alternative SBAS) within the MSR should be used to provide information for navigation integrity at user level but...

...EGNOS V3 alone is insufficient to address user-level integrity of maritime navigation due local noise, interference, multipath and non line-of-sight signal reception

- M-RAIM should be standardised within type approved MSR to protect the mariner from multiple simultaneous GNSS errors
- M-RAIM should be used in combination with EGNOS information, but could be used standalone if necessary

...but further work is needed

For M-RAIM, it is necessary to determine **a nominal vessel multi-path model**

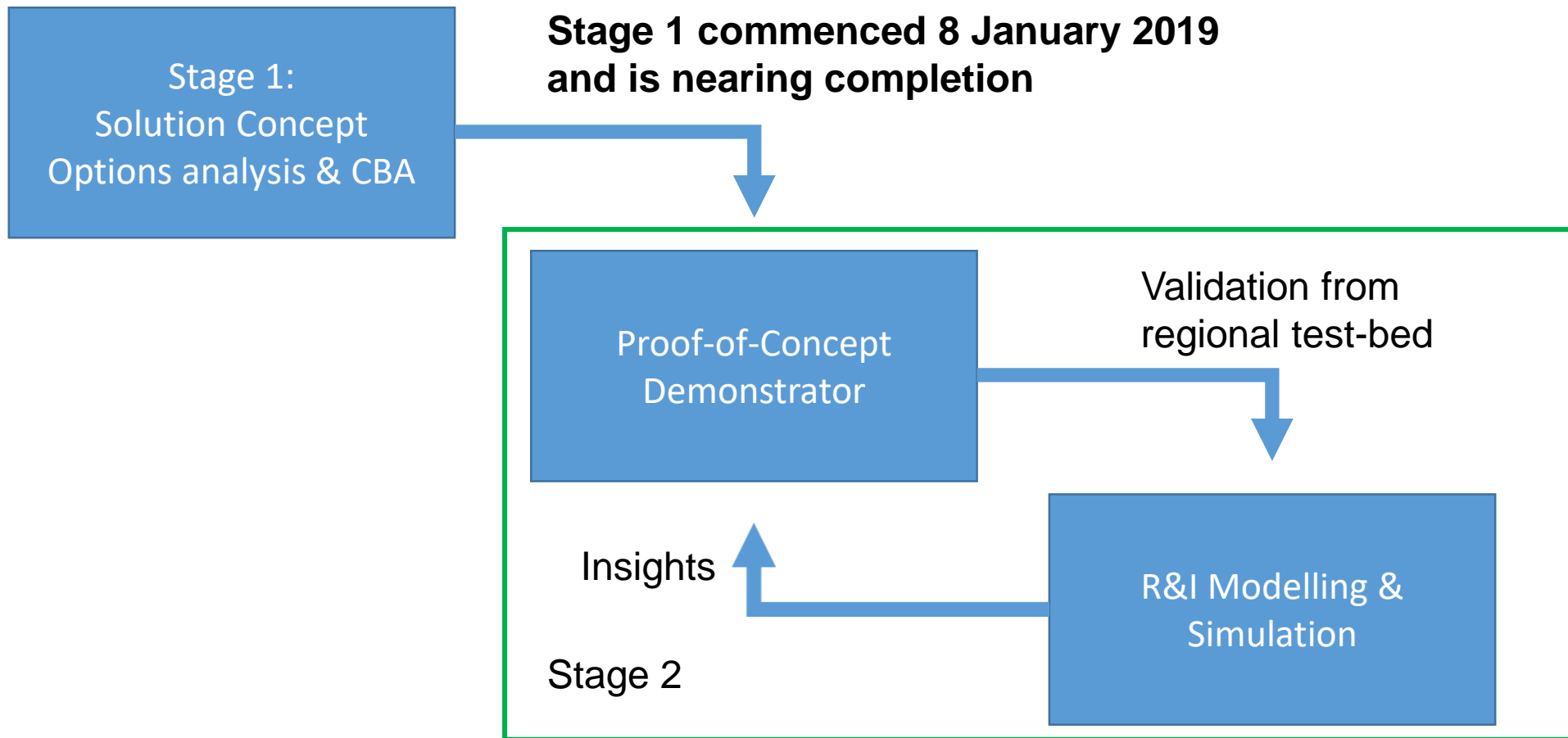
EGNOS V3 information for aviation is not ideal for maritime user-level integrity: provision of **underlying SBAS error statistics** would help

Advantages of **dual-frequency** L1/L5 (E1/E5a) use against the use of single-frequency L1/E1 or L5/E5a for maritime positioning should be investigated further by trade-off analysis

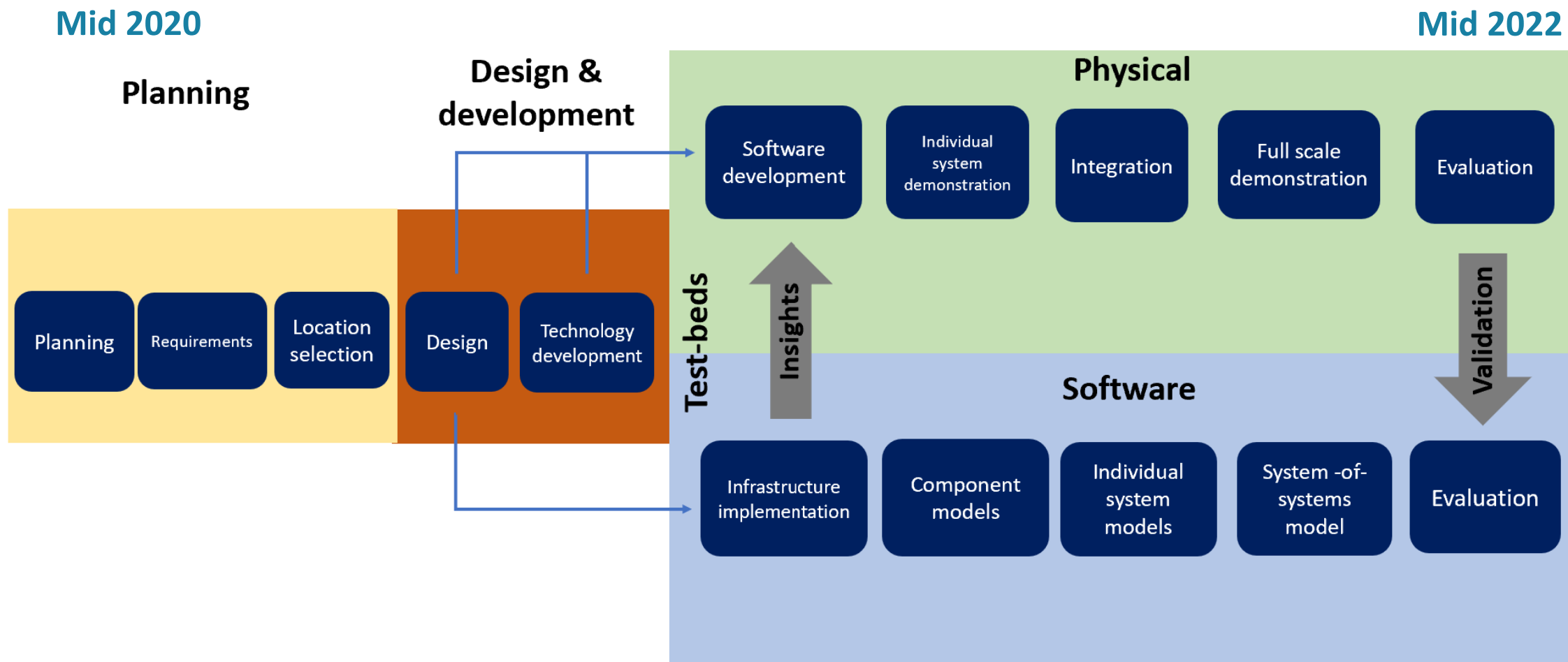
Future plans



Three year duration (1 year Stage 1 – possible Stage 2 over 2 years)



Proof of concept



Vision & benefits



Estimated benefits

Benefits

- economic loss resulting from unavailability of GNSS for a period of five consecutive days. The MarRINav System-of-Systems reduces the loss relative to the situation without it:
- assumes that one five-day outage occurs in the next 10 years

Costs include CAPEX and OPEX for all the systems included as part of the MarRINav System-of-Systems:

- eLoran
- Radar absolute positioning
- VDES R-mode
- LOCATA
- ePelorus

Benefits and costs	Value (£m)
Benefits (avoided loss)	421
Loss without MarRINav	601
Loss with MarRINav	180
Costs	200
Costs of on-shore infrastructure	80
Costs to shipowners	120
Net Present Value	+221
Benefit-cost ratio	2.2

Not in scope:

- Non-container traffic
- Non-maritime transport
- Terrestrial timing/synchronisation users