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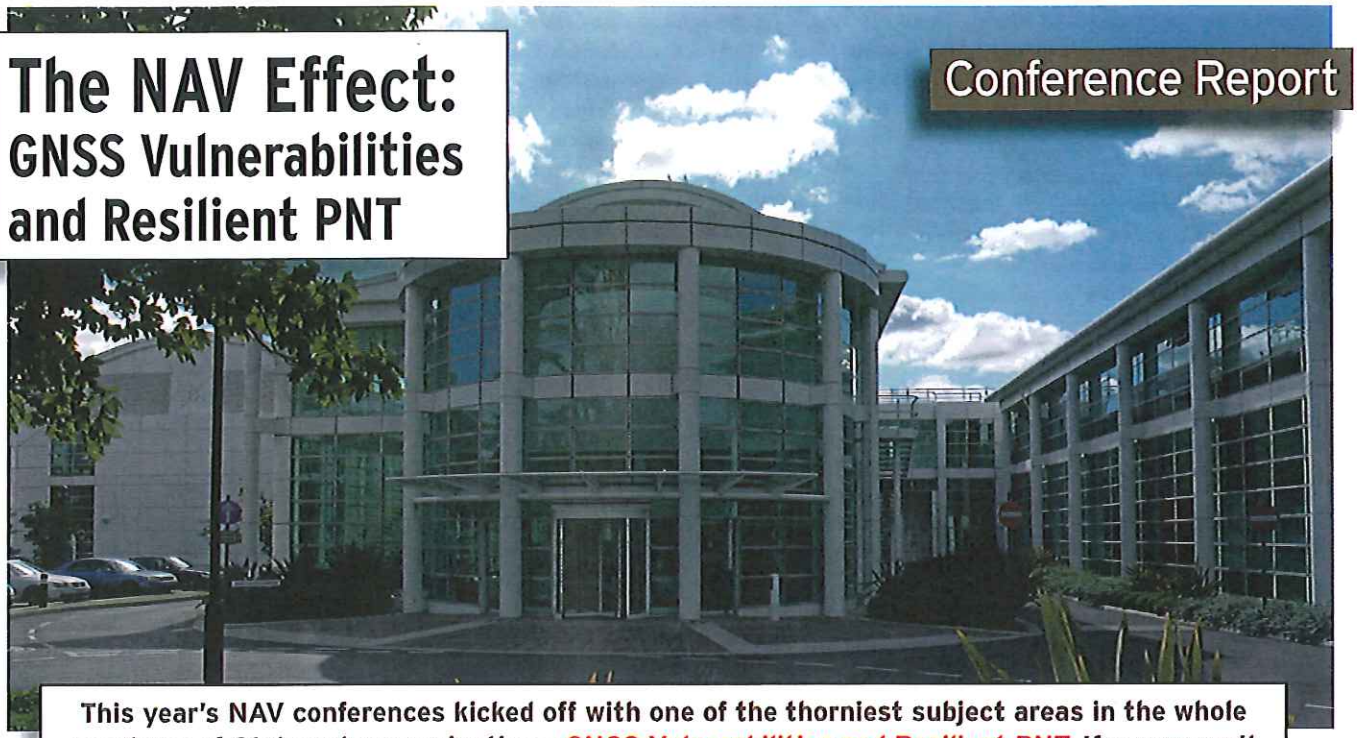
The NAV Effect: GNSS Vulnerabilities and Resilient PNT

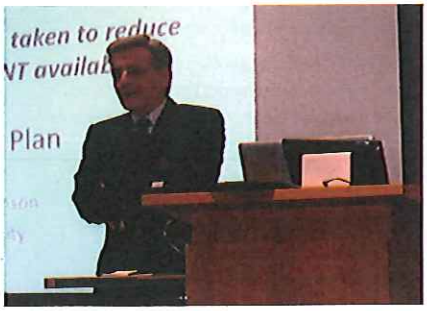
Conference Report



This year's NAV conferences kicked off with one of the thorniest subject areas in the whole spectrum of 21st century navigation - GNSS Vulnerabilities and Resilient PNT. If you weren't there, you missed out massively.

There's a thing that happens, when you get a lot of clever people in a room, and then allow truly original thinkers to speak to them. It's a slow, gentle bow wave of effects. The raised eyebrows inevitably give way to the widened eyes, to the bubbling inspiration in a hundred brains or more, and a sense of the universe being changed, but changed in a way that is so obvious after the event, so invigorated by that originality of thought, that Something Must Be Done as a result.

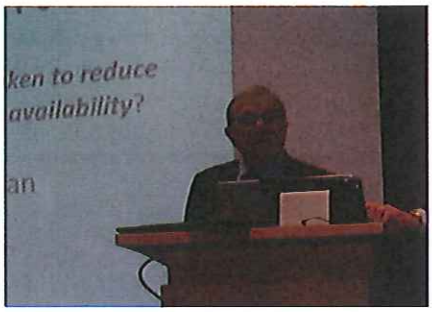
We call it the NAV Effect.



RIN President Roger McKinlay opens the conference

The Teddington PTA

The GNSS Vulnerabilities and Resilient PNT conference at the National Physical Laboratory on February 12-13 was a really good place to get your fix of the NAV Effect. Firstly, it opened up to a presentation from one of the minds behind the original GPS constellation, Professor Brad Parkinson FRIN. For a fuller understanding of the message he brought to the conference, read the lead feature of this issue, but his message of the need for a comprehensive and unified 'PTA' Plan – (Protect, Toughen, Augment) to address the understood and acknowledged vulnerabilities of GPS made audible sense to the audience at Teddington.



Professor Parkinson launches his PTA Plan.

Brad's plan, which included ensuring the spectrum for GPS was protected, toughening international responses to the manufacture, sale and use of jammers and spoofers, and the augmentation of GNSS by the deployment of a co-primary system with entirely different failure modes – as he said, 'finish eLoran, it's a low-cost solution' – would give users a completely different world in which to operate: a world where those who wanted to use jammers and spoofers would have far more of a challenge on their hands.

Playing Risk With Jammers

While the audience was still contemplating the potential of Brad's protected world, it was time to get seriously geo-political with Professor Jiwon Seo, who had come all the way from South Korea to explain that country's eagerness for eLoran.

'North Korea has jammed us regularly over the last three years. Their jammers are so powerful they can jam 100 km easily,' he said, silencing the hall with the contemplation of consequences.

He reported that the jamming had been particularly noticed on fishing boats which rely heavily on GPS – if jammed in low visibility they can not only crash into each other, but also unwittingly cross the border into North Korean waters.

Can we say 'pretext to a major international incident'?

Professor Seo tells delegates of North Korea's jamming.

The Electronics and Telecoms Research Institute of South Korea has observed and analysed North Korean jamming on L1, L2 and L5 bands, meaning the age of jamming as a geo-political weapon is now.

Between August 23-26, 2010, there were four days of jamming, affecting 181 cell towers and 15 aeroplanes.

Between March 4-14, 2011, there were 11 days of jamming, affecting 145 cell towers, 106 planes, and ten ships.

And between 28 April-13 May, 2012, there were 16 days of jamming, affecting 1016 planes and 254 ships.

'They can jam us any time – their technology is now mature, and clearly their testing has been effective. And if they sell it to terrorists, they can jam other countries too.'

Hence, he explained, South Korea feeling the need for a complementary PNT system – and choosing the most obviously effective contender, eLoran.

South Korea's current Loran-C chain comprises two stations in South Korea and two in Japan, with one more in Russia. Japan though is to discontinue its stations in December this year.

The South Korean eLoran system will eventually consist of five transmitter stations; two Loran-C stations at Pohand and Kwangju, and three new ones to be built.

However...

The South Korean eLoran program was initialised in October 2011 after North Korea's second jamming attack. The procurement process since then has been riddled with frustration and difficulty – bidding began in mid-November 2013... and failed when no participants came forward. The second procurement process... failed too, when only one bidder emerged, and anti-monopoly law declared that this could not be a fair procurement. The third procurement process, which began in January 2014... failed. There was still only one bidder, but this time the Government decided it would evaluate the bid.

Which it then rejected.

Now, the decision-making and procurement process may be further delayed due to a change in the leadership on February 6, 2014, following an oil spill in Yeosu. So while eLoran is accepted as the only electronic system that can provide the resiliency South Korea needs to stand up to North Korea's jamming-based aggression, it may yet be some time before the willingness to deploy the system is translated into any actual deployment.

Timing Is Money

Pedro Estrela PhD from the Netherlands was next to take the stage, and he illustrated a world rarely thought of in terms of GNSS resilience – the financial sector. In particular, Pedro showed how clock sync irregularities could cost the financial markets dear when, for instance, traders make purchases at prices they think are current, but which are actually several minutes old. He underlined the idea that in the financial world, it is network sync vulnerabilities that are more critical than standard GPS vulnerabilities.

Weathering The Storms

The University of Bath was well represented at the conference, and Professor Cathryn Mitchell was the first of its delegates to take the stage, to give an essential primer in the problems of and solutions to space weather as it impacts GNSS.

She highlighted issues like: ionespheric TEC – which delays signals, causing position error; ionospheric scintillation – which fades signals, causing position error/loss; solar radio burst – which fades the signals, causing position loss and; particle damage to satellites, leading to the loss of satellite operation. However, she added that mitigation and warning systems were the ways to reduce the impact of these effects, and that both areas were being addressed.

'Users are still out of step with research, though,' said Cathryn, 'and they don't know why systems are failing. Focussed research is needed to give specific bespoke diagnoses.'

Dr Sreeja Veettil from the University of Nottingham followed up Professor Mitchell's presentation with a more in-depth look at how exactly scintillation effects (specifically), are being mitigated to improve GNSS resilience in the modern world.

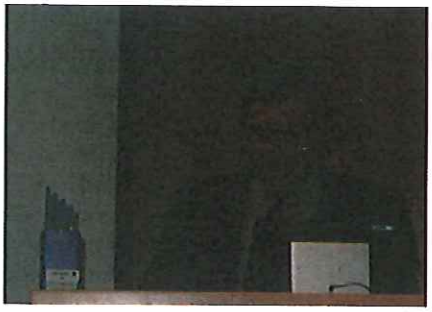
Black Swan

Professor Charles Curry, of Chronos UK and lately the Sentinel Project, took delegates back to basics and asked about 'Black Swans and White Elephants.'

'Black Swan Events,' he said, were by definition a surprise to the observer – though not necessarily to everyone – 'For example, Christmas is a Black Swan Event to the turkey, but not to the butcher,' he added, graphically.

'GPS is in everything, and people keep designing with it, unaware of the problems associated with it. Jammers are easily available – $200 gives you L1-L5 jamming. Police are now seizing this kind of device in the UK,' he added, to show the kind of proliferation of jamming devices that is now a UK reality.

Charles introduced delegates to the Sentinel Research Platform, a partnership with the University of Bath to develop a capability to rapidly determine which car a jammer is in – a key element, for instance, of Brad Parkinson's PTA plan.



Charles Curry never comes to conference without at least one jammer.

He outlined some ideas for mitigation of jamming, and questioned the assumption that Galileo's Public Regulated Service (PRS) would help reduce the risk of jamming.

As is occasionally necessary in a conference like this, Charles finished not by providing solutions, but by asking ongoing questions – 'When will the next Black Swan Event happen? Will Galileo fix the resilient PNT issue?'

Save The Cheerleader, Save The Superbowl

Joseph Rolli, from Excelis, a US firm, took delegates from the abstract notions of vulnerability and resilience to their first toe-dip into the practicalities of how resilience can be achieved, introducing the company's Signal Sentry 1000, which geolocates jamming sources. With resonances of the Sentinel Project in the UK, the Signal Sentry works by erecting a network of sensors around the event or location – Rolli pointed out that the 2014 Superbowl had been Signal Sentried – allowing for actionable intelligence at the point of need.

'The cops said to us "We're not scientists, we just want to find the bad guys"' Rolli added, 'which means the system has to be simple to use, and effective in what it delivers.' As a result, the US law enforcement community was involved in the development of the Signal Sentry.

Neil Gerein, NavWarrior.

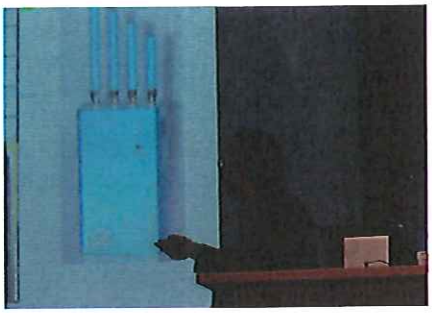
Neil Gerein, from NovAtel in Canada, took us from the civilian world and into the realm of NavWar to explain the principles of electronic protection, support – and attack.

Jammy Fingerprints

Picking up on Joseph Rolli's lead, meanwhile, Dr Mark Dumville, from Nottingham Scientific Limited, introduced delegates to the Detector Project – a technology for essentially 'fingerprinting' GNSS threats. 'Finding the threat is all very well,' he said, 'but how do you know what you're dealing with? Detector can tell you. Once you can baseline the threat, you can quantify it and react to it.' Why collect 'fingerprints' of jamming incidents?

Because there are identifying characteristics within jamming transmissions, said Dumville, which allows for the creation of a database of features, and the application of countermeasures to cancel out jamming effects – allowing a realistic fightback against those who use jammers and create either accidental or intentional chaos.

Dr Markus Kuhn added detail to the idea of resistance and resilience with his presentation on GNSS signal authentication and digital signatures as ways of ensuring the validity of any given GNSS signal. And picking up the thread of digital signatures, Dr Robert Watson, the second speaker from the University of Bath, asked a fundamental question – how hard is it to spoof a GNSS signal?



Dr Watson had also heard it was 'bring your jammer to work day'

'It's going to get easier as time goes on,' he said, meaning that as methods to repel, identify and neutralise jammers were coming to the fore, spoofers – means of controlling, rather than blocking, the reported time and position of a GNSS receiver – would become the bigger threat.

'You can't defeat spoofing with antennas,' he summarised. 'Digital signatures and the like – that's the way to go.'

He identified a significant potential threat in the electric power industry – spoofers could overstretch the grid - and further chilled the blood by reminding delegates that a spoofer was basically just a GNSS signal generator which could record and playback GNSS signals. That, he said, was not hard to build. Thankfully, a GNSS receiver initialised spoofer – which would receive and decode signals, make modifications and rebroadcast the signal, was a more complicated affair, so, he said, widespread development of sophisticated spoofers was unlikely.

For more from Dr Watson, check out your May-June issue of *Navigation News*.

Use Everything

Professor Wolfgang Schuster FRIN from Imperial College London argued for a more holistic approach to protection in the GNSS future, given GNSS current common failure modes, the potential for truly catastrophic failure events, and low user-level hardware resilience. He advocated integration of everything we have – data from integrity monitoring stations, networks of opportunity and dedicated networks of probes, like the Sentinel Project and the Signal Sentry.

And to end the first day of this NAV conference, Oscar Pozzobon from Qascom and Steve Hickling from Spirent introduced the delegates to SimSafe, a commercial test bed for the evaluation of GNSS receiver vulnerabilities – about which, you can read more on Page 10.

Navigating A Warzone

Day two of this landmark event opened up with the gods of irony playing pranks on delegates – in a room full of extremely clever and technical people, IT issues meant Rob Handley FRIN, from DSTL, lead the way, ahead of keynote speaker Ed Hinds. Rob took us back to the warzone, to explain how to get precision military navigation in the absence of GNSS. Terrain-referenced navigation was efficiently broken down for delegates into its two technical families – terrain contour navigation and linear feature mapping.

In the era of GNSS jamming, Rob said the MoD was funding research to improve the accuracy of MEMS inertial sensors, and develop more accurate chip-scales. The vulnerability of GNSS, he said, had heralded a return for alternative nav techniques.

Debbie Walter, from University College London took on Rob's baton and explored environmental features for non-GNSS navigation systems, particularly for road vehicles. Using terrain features, the built environment, and what would otherwise pass for a degree of natural navigation, she had created maps while GNSS was in service, which could then still be used if and when GNSS was lost. A cross-correlation achieved 100% accuracy, which makes the technology a promising development for the future.

No GPS Required

Mark Broster AFRIN, CEO of ECDIS Ltd, took the technological focus of the debate from the land to the sea, and asked conference one straightforward question – 'Do we need GNSS if we have ECDIS?'

'The answer's no. Thank you very much,' said Mark, succinctly. 'With new symbology, new charts, more sensor integration and radar overlays, there's no GPS required, really – just data and charts,' he explained.

If this wasn't a radical enough proposal for NAV delegates, the next speaker to the stage was guaranteed to blow minds. Professor Ed Hinds, from Imperial College London, told the crowd at Teddington about quantum technologies for PNT. He explained how extremely effective atoms could be for measurement, as they were calibrated by nature – one carbon atom was the same as another. When atoms move, their movement is characterised as a de Broglie wave, so atoms are also sensitive to length, and they have high internal frequencies, so they're sensitive to time. As tools for measurement, they therefore shape up very well.

Ed told conference about the use of atoms in interferometers and accelerometers, and how position uncertainty would grow over time, about atomic clocks, atomic oscillation and microwave oscillation. He added that there was now great scope to get the price down on reasonably accurate atomic-based clocks for PNT, which would drive forward what atomic research and navigation and timing research would be able to do together.

The Time of the Doctor

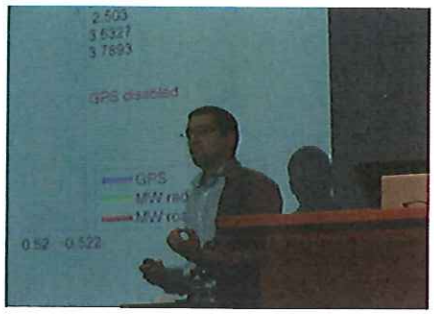
Continuing the theme of a brief history of time, the National Physical Laboratory's Dr Leon Lobo took delegates through the history and development of clocks and timing mechanisms at the Laboratory, leading to 'NPL Time' – a timing reference entirely independent of GNSS – which is a thing always worth knowing when the GNSS lights go out.

Resonating with Rob Handley's presentation, Dr Aled Catherall from Plextek Consulting showed off an optical navigation system for use in the GNSS-denied environment for urban soldiers.

Jam With Everything

Dr Ramsey Faragher MRIN from the University of Cambridge gave an evolution of a presentation that in itself was astounding enough to win 'lead feature' status in the July-August 2013 issue of *Navigation News*, on satellite navigation without the

satellites – using signals of opportunity to map areas and self-correct – 'navigation by *X Factor* and *Coronation Street*' as he put it with a characteristic wit that had conference chuckling. Particularly in regard to the challenge offered to would-be jammers though, Ramsey extended the scope of his work. 'If I'm navigating using just GNSS, then jammers have to hit only a particular band to leave me helpless and blind. If I'm using everything,' he added, echoing Wolfgang Schuster, 'then somebody trying to jam my system has to jam everything. That makes the challenge a lot harder, and they've then really got to want to do it.'



Dr Ramsey Faragher navigates by X-Factor.

The Unvarnished Truth

The NAV Effect – that blow-your-hair-back, eye-widening ripple of originality of thought, had been felt many times by the afternoon of the second day. It's fair to say though that conference wasn't ready for the arrival of Charles Schue FRIN, from US tech firm UrsaNav, when he got up to speak on resilience through co-primary PNT solutions; in essence, GNSS and eLoran.

In every conference worth attending, there will be one speaker who most embodies the Nav Effect (if you don't feel it, the conference probably hasn't been worth your time and money). Many attendees at the Teddington event felt – and indeed said – that Schue's uncompromising truth-telling most encapsulated the essence of the effect this time round.

Charles Schue - Truthteller Extraordinary.

'GNSS vulnerabilities are well known,' he said, going on to highlight the main ones - unintentional jamming, unintentional but collateral jamming, overt intentional disruptions and so on. 'Who can build a jammer?' he asked. 'Anyone with a Bachelors in Engineering, certainly. But essentially, anyone with a reasonable understanding of engineering principles and access to the web. The need is for resilience. GNSS resilience has a name – its name is eLoran.' He went on to remind conference that 'every study and report has the same conclusion. GNSS is vulnerable. eLoran is the best alternative – discussion over.'

He gave a list of alternatives to GNSS, and then explained simply why none of them were co-primary – why none of them fit the bill as a parallel system to GNSS.

Except eLoran.

'Our nation's safety and economy should not rely on one vulnerable system,' he said, provoking solid murmurs of agreement and relief from the crowd. He explained how UrsaNav had been working with the University of Texas and smart grid providers, to show eLoran as co-primary for an electrical power grid. eLoran had performed on par with GPS.

Finally, he gave a round-up of countries leading the way in providing resilience through eLoran – including the UK, South Korea, and then with decreasing certainty, China, Saudi Arabia, India, Russia and Iran.

> 'If I'm navigating using just GNSS, then jammers have to hit only a particular band to leave me helpless and blind....'

As for the US... Schue outlined a way in which political considerations, which have dogged the adoption of eLoran, could be circumnavigated through a potential public-private partnership. For more detail on Charles Schue's presentation at Teddington, see your May-June *Navigation News*.

Underlining with hard research what was becoming the theme of the conference – GNSS-alone vulnerable, GNSS+eLoran comparatively safe - Dr Alan Grant FRIN, from the UK General Lighthouse Authorities (GLAs) showed what eLoran could do as a co-primary system on ships, by virtue of comparative footage of a jamming trial on board a GLA vessel in the situation of GNSS-only navigation – chaos, alarms, demented readings, less demented but still wrong readings, and the essential turning of a lot of expensive hardware into a very boring disco – and the same jamming trial run with the vessel equipped with GNSS+eLoran – no lights, no chaos, a simple, seamless, automatic transfer of primary navigation function from GNSS to eLoran.

Knight Rider... Coming Soon

Chi Hay Tong from the University of Oxford took much of the automated vehicle research to the next level with his presentation on modern robotics for smart transport. He made it plain that for safe self-driving cars, GPS coupled with inertial systems simply wasn't good enough. He introduced what might be thought of as 'one turn at a time' navigation – Relative Frame Navigation - with the idea that when backing out of our driveway, we don't need to know there's a roundabout down the road – and that when we're at the roundabout, we don't need to know where our toothbrush is. The idea of being locally metric but not globally consistent is an easier way of teaching cars to drive.

His system of robotics for smart transport involves using stereo cameras to give 3D navigation through stereo visual odometry. Then you simply drive, and teach the car's sensors bits of the map. In a second, 'repeat' phase, the car will find itself the relevant maps as you drive along.

Finally before the conference's plenary session, Dr Chaz Dixon FRIN from the Satellite Applications Catapult talked conference through the Galileo Public Regulated System – what it will be able to bring to the world of GNSS resilience, and what it won't. For more from Chaz, see the May-June issue of *Navigation News*.

The Mood of the Conference

In summing up the conference, a panel of experts was invited to theorise, and the delegates were invited to add their thoughts. Rear Admiral Nick Lambert, former UK Hydrographer, joined Professor David Last, Professor Terry Moore from the University of Nottingham and Professor Jiwon Seo from Yonsei University, while the plenary was hosted by Professor Brad Parkinson.

'What are the worst threats to GNSS?' asked Professor Parkinson.

Nick Lambert staked a claim for the human interface, and the training of the operator. Professor Last said there was currently 'nothing to prevent a major incident in the English Channel. We'll see one with very serious consequences. There will be collisions. We have badly trained people bringing very big ships in very great numbers through a very narrow channel. We're just waiting for the incident.'

Professor Moore said the key danger was an 'ignorance of impact.' He cited an incident in San Diego in 2007, when hospital pagers stopped working, and no-one understood why. He added that the ionsphere was also a big threat, because 'people don't want to know about it because it's technical.'

Professor Seo's concerns were closer to home – 'fishing boats crossing the border.'

When the question of the greatest threat was thrown open to the audience, the mood of delegates was summed up by Chair of the RIN's Technical Committee, Sally Basker. Considering the greatest threat to GPS, Sally said 'political prioritisation and the naivety of decision-makers.' Brad Parkinson agreed. 'Well... that's likely. And actually, pretty dangerous too.'

Addressing the political question, Professor David Last shared Sally's gloomy outlook.

'We're behind the US by about five years,' he said. 'Time after time at this conference, we've heard of the vulnerability of GNSS. We've heard of the need for resilience through a co-primary system; that that system is eLoran. But where are the ESA at this conference? Where are the politicians? They're not here. They're not here because they believe the great myth. The great myth of Europe is that Galileo PRS is the solution, and that the maritime world just needs to do what aviation has done. And it's a myth that will kill us.'

That, said Professor Parkinson, was why he had come to the conference: to educate, to spread the word, to persuade for a robust co-primary system, to protect, toughen and augment GNSS, to make it harder and less attractive to jam and spoof, and above all, to break through the wall of political inertia and apathy.

That is a mission that every reader of *Navigation News* can help achieve. 'The myth will kill us.' The truth about GNSS vulnerability, and the potential that now exists to establish resilient PNT, can only set us free and make our world, our national and our international infrastructures, stronger and safer against accident and attack.

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