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Use of 3D Scanning Technologies and Virtual Reality to Validate Transport Operations Interfaces

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Abstract

International Nuclear Services (INS) is a wholly-owned subsidiary of the UK Nuclear Decommissioning Authority (NDA). INS has extensive proven expertise in providing strategic assessments, consultancy services and feasibility studies relating to irradiated fuel management and worldwide nuclear material transportation by road, rail and sea. It also has significant experience of package selection, design, finite element analysis, engineering and licencing; and operates a fleet of maritime vessels via a partially owned subsidiary company; Pacific Nuclear Transport Limited (PNTL).

INS' use of 3D scan data to validate transport operations was presented at PATRAM 2016. The methodology of manipulating 3D point cloud data of ship holds and analysing them in conjunction with 3D CAD models of transport packages was presented, along with potential opportunities going forward regards how the technology's benefits could be optimised.

This paper develops on the ideas that were presented in 2016. It details the recent developments INS has made in utilising 3D mapping technology (such as service provision and Virtual Reality) that expand on those proposed in the 2016 paper. It goes on to envisage how INS will further develop the use of 3D point cloud Data and Virtual Reality in other areas of the business to realise further benefits in respect of costs, resource requirements, personnel safety, asset availability and general preparedness for complex, safety critical operations. Examples of business areas in INS that could benefit from this technology range from Engineering, Transport Operations, and Environmental Health and Safety to Commercial Sales and Human Resources.

1 Definitions and Abbreviations

CAD	Computer Aided Design
FEA	Finite Element Analysis
INS	International Nuclear Services
LB	Lifting Beam
NDA	Nuclear Decommissioning Authority
PS	Parking Stand
RAM	Radioactive Material
Point Cloud	A set of data points in a virtual 3D space, composed of multiple 3D scans
3D Scan	Point Cloud generated using a 3D scanner
Registration	The process of 'stitching' multiple 3D scans together
VR	Virtual Reality

2 Introduction

INS has over 45 years' experience of transporting nuclear cargo by road, rail and sea. For each consignment, given the sensitive nature of the nuclear industry, there is significant emphasis on ensuring that every stage of the transport will proceed without disruption and as efficiently as possible. Such transports inherently consist of multiple, complex procedures relying on various interfacing equipment from torque wrenches; vent purging valves; and lifting beams to high-mass nuclear transport packages; ship holds; and nuclear plant facilities. This range of equipment has significantly varying characteristics and therefore, during the transport preparation stage significant effort is dedicated to ensuring maximised confidence in the compatibility between interfacing equipment.

INS submitted a Paper at PATRAM 2016 that presented the process that was adopted as a means of exploring the potential for increasing confidence during pre-transport preparations [1]. It detailed the application of 3D scan data to assess the compatibility of RAM transport packages on a NDA vessel. The approach allowed for increased understanding of static and dynamic clearances between the vessel and packages with much greater accuracy than had previously been achieved. As a result of adopting this approach, many additional benefits were realised, with potential not only in nuclear transport, but elsewhere in the industry. Such highlighted benefits included;

- Reduced reliance on asset availability for assessments, design activities and cold trials.
- Reduced cost for completion of work
- Reduced human resource requirements
- Reduced time scales
- Optimisation of cold trialling
- Quick office based familiarisation of the vessels for anybody who requires it
- Reduced Health and Safety risks

Since 2016, INS has continued to use the 3D scan data that it had commissioned with ever increasing frequency, developing the methodology of identifying suitable transport solutions. Due to ever increasing use and understanding of this technology, INS has now acquired the capability to conduct 3D scans in house, as opposed to simply assessing existing 3D scan data provided by 3rd parties. Not only that, but a push to further develop the technology and add peripheral supporting technology to broaden its application has been ongoing in INS since the last PATRAM. This has allowed INS to optimise the above benefits further whilst addressing some of the limitations identified in [1] and developing the future opportunities also highlighted in [1]:

Opportunities

- Informing design decisions through virtual spatial testing of CAD models
- End to end transport simulation through virtual environment
- Hard to access areas e.g. health and safety or security restrictions

Limitations

- No firm assessment of operational clearances
- No means of updating scans in line with physical modifications to assets

This Paper gives an update on where INS is with the application of such technologies. It gives examples of how it has been applied (drawing comparisons with the 2016 capability), current developments that are ongoing, and looks forward to give an idea of how INS intends to further optimise the use of this exciting technology.

3 Application of 3D Scanning Technology since 2016

This section details some of the 3D scanning that INS has conducted in recent years, highlighting the benefits identified prior to the work (i.e. justification for scanning) and any further opportunities or limitations identified as a result of the work.

3.1 3D Point Cloud Updates following Asset Modifications

When fitting a transport frame into a flask seat position on board one of the maritime vessels, it was found that the clearance between the transport frame and the guide features on the vessel were more restrictive than had been expected. As a result, a partial obstruction was caused during lowering operations. At the time, INS had the 3D scan data of the hold vessels that could be used to check against the features in the Hold (the same scan data that was referred to heavily in [1]). However, given the varied nature of shipments that INS conduct, the vessel flask seat features are susceptible to modifications that render aspects of the vessel's 3D point cloud data time dependant. When considering an evaluation of the hold space, it was therefore agreed that the vessels' scan data should be updated using the newly acquired 3D scanning capability. Not only would this provide quality assured data, it would also upgrade the quality of scans. INS completing these scans enabled definition of the required scan resolution depending on the pertinence of certain features on the vessels. There was also the new capability of generating the scans in colour.

Detailed scans were taken to generate a 3D point cloud of the vessel. Photographs were taken in conjunction with the scans that were used to render them and could be used to create a photorealistic environment with underlying point cloud data, from which any number of measurements could be taken. Although this may initially seem like a superficial 'nice-to-have', it significantly enhances investigation of the point cloud by reducing assessment times and allowing findings to be conveyed to stakeholders in greatly reduced times.

A direct comparison of the historic data (left) and the newly acquired data (right) are shown in Figure 1.

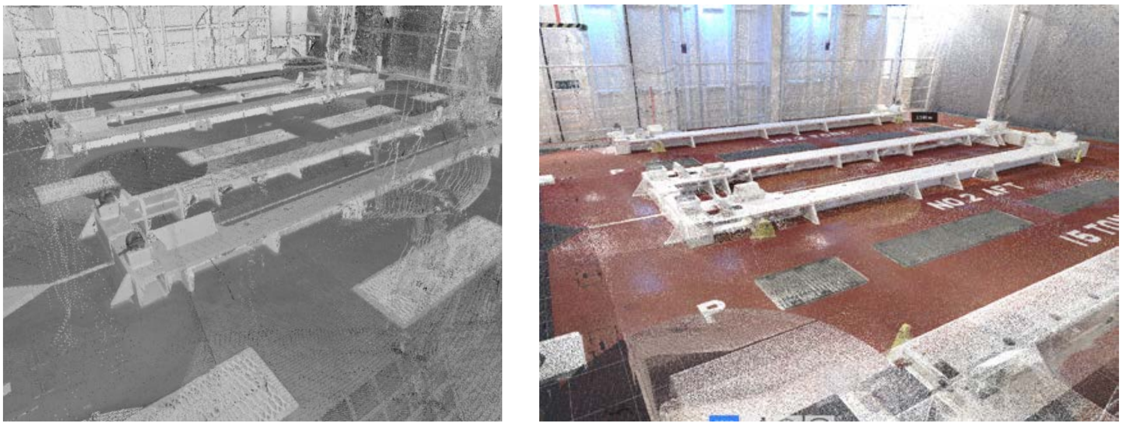

Figure 1 -- Comparison of previous (left) vs new (right) 3D output data

INS now has updated scans of the vessels that were produced in-house. If there are any modifications to the vessels that can potentially effect transports, the relevant areas can be scanned and incorporated into the vessel point cloud as opposed to rescanning a vessel in its entirety. Furthermore, as INS generated the raw data in the first place, it allows for conversion of the data into a file format for the particular software platform that is most appropriate for the task.

3.2 Scanning of Assets upon Receipt from Manufacturer

In 2018, INS designed a Lifting Beam (LB) and associated stowage Parking Stand (PS) for a RAM transport package. Following manufacture, INS took receipt of the LB and PS in May 2019. Even though there was no specific task that required scanning of these assets, INS decided to do so regardless. Given the low investment of time, and the large envelop dimensions of the LB and PS it was deemed appropriate to create a point cloud of the newly manufactured asset (Figure 2). This allowed INS to obtain a comprehensive set of data representing the 'as built' condition, meaning the LB and PS can be tested in a virtual environment for compatibility with interfacing assets. Not only would this lend itself to testing on the intended transport vessels, but it would also provide valuable insight if; a requirement to lift alternative packages with similar dimensions arose; there was a need to use an alternative transport method e.g. road or rail; or the lifting beam was being used on a different site from those initially intended. The latter was of particular interest as the shackle arm assembly was designed to fit two specific Ramshorn hooks with limited clearance. If an alternative site proposed the use of a different Ramshorn hook, it could be offered up in the 3D point cloud to assess compatibility.

It is also worth noting that for this particular design, there were a number of design modifications undertaken during manufacture, all off which would be captured in the 3D Point cloud.

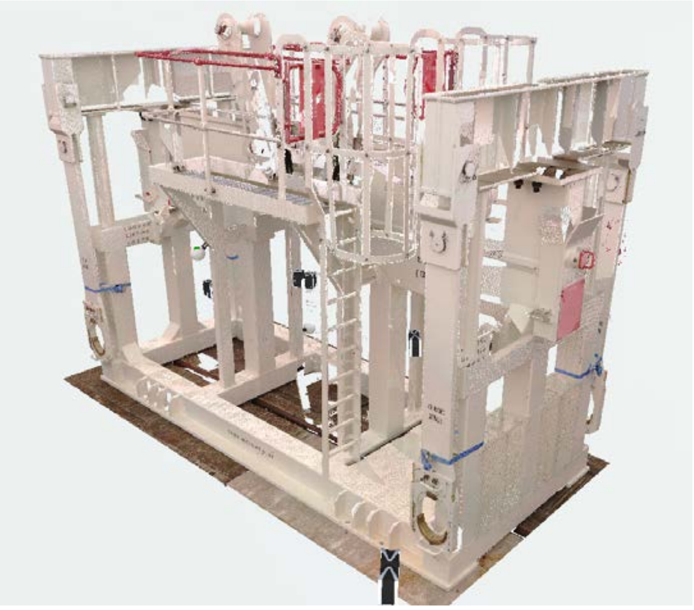

Figure 2 - 3D Point Cloud of Lifting Beam and Parking Stand

Given the bespoke nature of the LB and PS and that there was only one-off manufactured, it lent itself well to being scanned for recording in a 'virtual environment'. If large quantities were manufactured, it would be difficult to justify 3D scanning of the full fleet. However, it is worth considering the following when producing high quantities and 3D scanning;

1. For the case of the LB and PS (i.e. fabricated assemblies), tolerances are relatively generous and scanning one of a large fleet would most likely provide a sufficient representation of all items.
2. If the design intent required more refined tolerancing, it would be conceivable to gain an understanding of the maximum and minimum as-built condition. If the difference was deemed relevant to operations, the two bounding assets could be scanned (i.e. the maximum and minimum condition) for future reference.

3.3 Inspection of manufactured assets

A number of transport frames were manufactured that were designed to restrain RAM transport packages. Following manufacture it was found that the clearance between the package and the transport frame were not as required by the design. Throughout the manufacture of the frames, vigorous inspection had verified the as-builts against the associated drawings and it was therefore queried if a build-up of tolerances had created an unexpected error. To get a detailed understanding of the relationship between multiple features in a fabricated and assembled state, the scanner was deployed. Figure 3 shows registered point cloud and Figure 4 shows an example of measurements being taken directly from the photorealistic virtual environment. The semi-transparent spheres in Figure 4 show the positions from which each scan was taken.

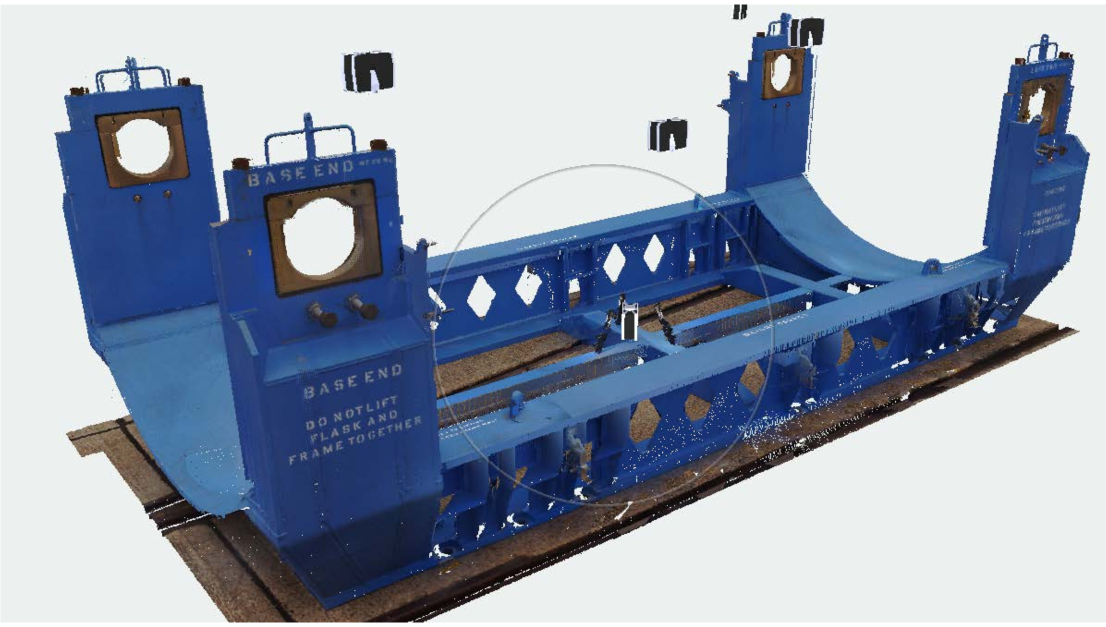

Figure 3 - Point Cloud of transport fame

Figure 4 - Point cloud of Transport Frame overlaid with photography

The main justification for 3D scanning in this case was the need to understand the ‘x’ ‘y’ ‘z’ components of dimensions that spanned large distances in angles that were oblique to the main axes of the transport frame. An example of such a dimension was between the stanchion and cross member as shown in Figure 4. Such dimensions could then be cross referenced with the equivalent dimensions in the CAD model to understand if there were any variations.

Additional benefits that were realised was the power of utilising photorealistic environments to investigate the point cloud as well as the increased ease of use just from using colourised scans. Much like the benefits detailed in Section 3.1, it significantly decreased assessment time and helped to convey findings to internal stakeholders in much reduced times.

3.4 Support to Validation of 1/3 scale model

INS was tasked with validating a detailed impact assessment model using Finite Element Analysis (FEA) against a physical drop test. The physical drop test was completed on a 1/3 scale model of a Radioactive Material (RAM) transport package circa 2004/5. As part of the validation process, it was deemed necessary to take physical measurements of the dropped package to understand the impact deformations.

A visit to the location of the scale model was organised to conduct the physical measurements. However, given security requirements for access to the site, the man hours required to get to site and conduct the survey (coupled with the associated general health and safety implications) and the cost involved, it was deemed prudent to make the most of the visit by conducting 3D scans of the scale package whilst onsite. As a result, INS could complete the onsite survey knowing that the maximum amount of data had been gathered. Therefore, should validation of the FEA model require additional physical measurements that were not identified at the time of surveying, the data would be available to INS immediately. This would negate the need for unplanned future site visits along with the associated time and expense to INS and the client.

3D scans were therefore completed for the scale model along with the planned physical measurements. Once the scans had been registered, the 3D point cloud was verified by taking measurements at the same locations as the physical measurements.

Figure 5 shows images of the scale model point cloud with verification measurements.

Figure 5 – 1/3 Scale Model (Left), Point Cloud Model (Middle), Verification Measurements (Right)

The point cloud of the scale model was verified to be a sufficient representation. There were points of learning that INS gained from this project, which would allow for greater efficiency. It was found that the irregular nature of the scale model's surface due to the impact tests made registration of some scans more difficult than expected and that the software INS originally intended to use for measuring the point cloud was not appropriate. As a result, an alternative was used in its place, which greatly enhanced the quality of output as well as INS' understanding of the intricate strengths and weaknesses of the three software packages that have been acquired for such investigative tasks. Originally, INS had intended to procure alternative software to take the place of the tools it made use of when first using 3D scan technologies. However, this project contributed towards understanding the need for multiple software packages in order to maintain versatility of assets that can be scanned and how they can be interrogated.

4 Currently developing

This section highlights the 3D scanning capabilities that are under development in INS, whilst looking ahead to the opportunities that can be realised as a result.

4.1 Visualisation of Asset Register

In addition to the benefits of 3D scanning highlighted throughout Section 3, there is possibility to develop a ‘virtual asset register’ that displays all assets in one Virtual Environment. This is in progress and development to date has been achieved using the assets that have already been scanned through day to day activities (Figure 6). Continuing the trend of scanning assets as they are manufactured would allow them to be stored on a virtual quayside next to a full fleet of maritime vessels, rail wagons and road vehicles. It would also include ancillary equipment such as lifting apparatus and allow for initial and quick compatibility assessments within the one 3D point cloud ‘file’ to be conducted, providing an interrogable visualisation of INS’ asset register.

It was mentioned in [1] that one of INS’ aspirations for future use for 3D scanning technologies is to simulate end to end transports (i.e. export facility through to import facility and everything in-between) in a virtual environment. INS’ visualisation of its asset register is the initial step towards this aspiration. Developing the capability offline by gaining an understanding of the required software and using INS owned assets to generate sufficient quality scans of equipment that is understood in detail will give INS a strong foundation going forward. As described in [1], this would increase preparedness before any cold trialling whilst optimising the associated operations. It will also be possible to construct the virtual environment with quick access to all the salient information about assets such as package materials and shielding thicknesses.

In addition to those mentioned above, there are a number of other benefits that that could be realised through use of a visualised asset register, as detailed in the following paragraphs.

4.1.1 Re-purposing of Assets

In recent years, INS has facilitated a number of complex nuclear transports, a high proportion of which have been optimised through innovative re-purposing of existing assets. This approach has potential to significantly reduce the time and cost when developing suitable transport solutions. The ability to visualise an asset register would further optimise the process of scrutinising potential assets and recognising any suitability.

4.1.2 Enhanced Teleconferencing

INS interacts with international clients on a regular basis. Although it is widely recognised that face to face meetings are a necessity to aid successful transport solutions, it must also be recognised that increasing numbers of meetings are being held through teleconferencing and video links. This is not only cost saving, but reduces risks to the travelling employees and increases wellbeing. With a visualised asset register, the productivity of such teleconferences could be enhanced greatly. It would provide the ability to conduct virtual tours (of vessels, quaysides, plant facilities etc.) and to convey proposed solutions in far greater detail, iterating the preferred approach before making the required financial and time commitments to facilitate a face to face meeting.

4.1.3 Conferences

In an industry where knowledge sharing is vital, numerous technical conferences are organised where challenges, ideas and ways forward are presented. With a visualised asset register, there is an ability to convey and feedback to challenges that are being presented at the conference. If it is known that transport assets can be assessed (albeit to a high level) for compatibility with other attendee’s equipment it would help to clarify what are knowns and any required assumptions at conferences. Such symposiums could become a forum for live testing of CAD model’s compatibility with potential service provider’s assets and facilities. To a certain extent, high level feasibility simulations of transports could be conducted at the front end, during initial discussions. For instance, if a CAD model of a Transport Package was brought to a conference, a high level virtual assessment of the package’s compatibility with transport assets such as vessels, rail wagons and lifting equipment could be conducted almost immediately.

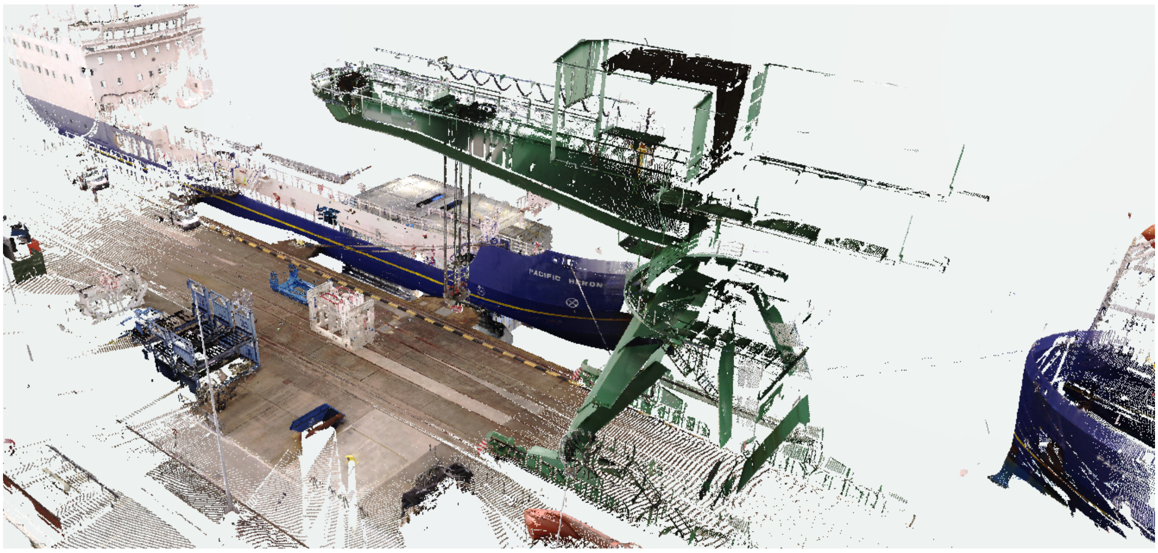

Figure 6 - INS' Visualised Asset Register to date

4.2 Virtual Reality (VR) Assessments

VR has been used at conferences in the past to explore CAD models and present proposed solutions for complex challenges. It is also deployed regularly as part of the design process to assess the ergonomics of proposed solutions, usually in a CAD environment. Although INS has not to date had reason to use VR for these purposes, an opportunity surrounding the use of 3D scanning technologies has been identified. This is partly due to the limitations in assessing the suitability for operations on the maritime vessels, as highlighted in [1]. Given the complex geometry of the vessel holds, it is not viable to commission detailed CAD models of the hold spaces and convert them into a VR environment. However, INS has the ability to convert all the generated 3D scanned data into VR. Given that there is already justification to scan the assets, the additional steps required to generate VR are extremely minor.

In conjunction with the visualised asset register (Section 4.1), VR is a powerful illustrative tool (See Figure 6). Its uses would include virtual tours, spatial assessments and demonstrations at conferences. Furthermore, INS intends to combine the photorealistic point cloud environment with VR capability resulting in a fully immersive environment, conveying better understanding to clients with a sense of realism, scale and technical detail second only to that of an actual visit and at a fraction of the expense.

In addition to the above, by combining CAD designs (or existing scanned assets for that matter) with 3D scan data of work environments such as plant facilities or vessels in VR, INS can expand on the spatial studies previously conducted by introducing an element of operational and ergonomic assessment of transport solutions prior to the manufacture stage, or prior to committing the time and expense associated with bringing two existing assets together for cold trialling. Once this capability has been well established within INS, it will be possible to further expand the uses of the virtual environment; for training opportunities; to communicate understanding of operational challenges to those that are not subject matter experts (e.g. to influence designs as early as possible); or to support interview activities such as scenario simulation. Incorporation of environmental simulation will also be explored. For instance, if weather i.e. wind conditions can be accurately simulated in the virtual environment, it may be the case that a less conservative wind speed limit that is still operationally safe could be identified.

Figure 7 – VR in Visualised Asset Register

5 Conclusion

Previously, INS held 3D scan data of the fleet of PNTL vessels that had been commissioned in 2012 as well as software for manipulating the 3D point cloud. The data was provided by 3rd parties and intended for taking measurements, conducting spatial assessments and performing clash detection between interfacing assets. INS conducted a limited number of spatial assessments and as a result, realised the further potential of such technology. Since 2016, INS has developed its 3D scanning capability and the applications for which it is used.

The capability now includes;

- Generation of scan data. This includes post processing, registration and export of 3D scans to the required format.
- Combination of separate 3D point cloud projects. This facilitates the likes of updating existing 3D point cloud data following modifications to assets and visualisation of INS' asset register
- Colourisation for enhanced assessment
- Photorealistic investigation of 3D point cloud
- Conversion of scans into VR allowing virtual tours, operational assessments and operator familiarisation

The above capabilities consist of a combination of hardware and multiple software platforms which are used in varying combinations depending on the desired output. This capability is now engrained in INS' day to day activities and is primarily used to better understand the challenges of RAM transports whenever possible to do so, with specific approaches varying greatly depending on the particular challenge. Using this to form a strong foundation in the technology, INS intends to further expand its use to enhance continual communication with international clients / stakeholders, incorporate operational assessments and simulate environmental conditions. Table 1 summarises the development of INS' 3D scanning capabilities.

Table 1 – Summary of INS 3D scanning capabilities

Capability	**2016**	**2019**	**2021**
Possession of monochromatic 3D point cloud data of vessels	x	x	x
Point cloud dimensional assessment	x	x	x
Clash detection	x	x	x
Scanning capability (conduct scans, process, register, export to required format)		x	x
Real view dimensional assessment		x	x
Virtual reality		x	x
Virtual tours		x	x
Operational assessment			x
Completed visualised asset register			x
Real view VR (combination of 3D VR and real view point cloud assessment)			x

6 References

[1] S. Porter, “Use of 3D Scanning Technologies to Validate Transport Operations Interfaces,” 2016.