# Charting the Course: Navigating the Royal Navy's Autonomous Challenge with Synthetic Assurance.

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**Synopsis**

The Royal Navy (RN) has all but declared its hand that autonomous surface systems will form a significant part of its fleet as it moves into the Navy after next. The Maritime Operating Concept (MarOpC) signposts autonomy five times. The RN needs ships to deliver credible military effect, autonomy can help increase mass, reduce crewing and complete tasks ultimately with little or no oversight of most systems.

Small boats such as the Autonomous Pacific 24 (APAC24) are forming part of the answer, increasing capability for larger more conventional platforms. For the RN to enjoy the benefits of autonomy they will need to move away from remote control IMO Degree 3 and into the world of ship autonomy in IMO Degree 4. If this is possible, it is a win for defence, but how do, we get there? We are currently grappling with the challenges of small boats and degree 3.

Historically, naval ships are built to naval codes which stem from their commercial equivalents adding to the military delta. Nothing is expected from the International Maritime Organisation (IMO) in terms of legislation until at least 2025 and the Maritime and Coastguard Agency only just released a workboat code annexe to support the regulation of remote-operated systems less than 24 meters. The RN does not have the luxury of well-defined regulation and almost by accident, they have become the front line in the regulation space placing pressure on getting it right. These highly autonomous platforms have a significant amount invested in the sensor suite and ultimately the decision engine will likely be AI-based, so how can you regulate these?

Synthetic environments might be part of the answer and this paper looks at where synthetics have been used before to support regulatory outputs, the limitations of the current methods already implemented and how these might be optimised to install trust in the systems before going to sea. We already accept computer modelling for regulatory purposes in other areas, however, never with the stakes so high.

Many elements go into the validation of the synthetic model before this is even able to be useful to validate the autonomy system itself- this paper explores these and how the challenge might be tackled. It will also explore some of the interdependencies that will be required to make the synthetic testing credible.

Keywords: Autonomy, Naval Certification, Trust in Autonomy, Synthetic testing, Validation

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A chartered marine engineer employed as NavyX's experimentation and project delivery team lead. He has a MSc in marine engineering, he started as a seagoing merchant navy engineering officer before moving ashore with Wartsila. Later he moved to Lloyds Register as an engineering systems specialist. Areas of interest are marine autonomy, alternative fuels, and the use of novel technology with a maritime application.

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## 1. Introduction: The Problem

The Royal Navy has indicated its intention to use marine autonomy, as cited in the Maritime Operating Concept (MarOpC) (Royal Navy, 2022). The Navy also has several autonomy-related programmes, the Mine Hunting Capability Programme uses autonomous vessels to deliver its effect. (DE&S, n.d.). NavyX is the Royal Navy's Autonomy, Lethality and innovation accelerator and has seen the introduction of the Autonomous Pacific 24 and Maritime Demonstrator For Operational eXperimentation (MADFOX) both have enabled NavyX to learn how to operate autonomous assets (Royal Navy, 2024). Whilst these boats offer a good step towards autonomy, it is clear that large ship, human out of the loop autonomy is required to deliver the Navy's demands for the future. The Navy has a problem, whilst autonomy is a developing technology for the commercial sector, the RN will want to use it differently.

This report seeks to address some of the challenges around assuring the navigation element of the systems. Currently, there is a significant gap if we look at the whole platform: engine room watch keeping, machinery reliability and management of fuel, just a few areas that will see significant change.

## 2. Where Synthetic assurance has been used before

The use of synthetic assurance or computer-based modelling for the assurance of systems is not new, as demonstrated by the use of Computational Fluid Dynamics (CFD) being accepted in scaling ballast water treatment systems. The International Maritime Organisation (IMO) provide Guidance on the Scaling of Ballast Water Management Systems. It accepts mathematical modelling using CFD, however, it clearly states, that the modelling should be experimentally validated and that it should demonstrate the accuracy of the mathematical model (International Maritime Organisation, 2018).

Google's autonomous car Waymo Driver has done billions of simulation miles and then millions of actual driving, this is just an indication of the amount of data required (Waymo, 2024). Equally comparable is Ford's BlueCruise which is approved for hands-off supervised driving in the UK but only on very restricted routes and after significant simulation and real-world driving. This Level 2[1] the system is low in terms of 'quantity' of automation and there has been significant work to get there (Ford, 2024).

The use of synthetic assurance whilst commonplace is done with a good stakeholder engagement foundation where all parties (Developer, user and regulator) are aware of the assurance pathway and how the data sets have been obtained. Any deviation from this plan inserts dis-trust and therefore a loss in the credibility of the data. Keep in mind that George Box a British statistician stated, 'All models are wrong, but some are useful'.

## 3. The challenges of autonomy assurance vs normal assurance

Why do we need something different? Can autonomous systems be assured more conventionally? For the most part, they can, when there are well-founded methods, rules and regulations for elements such as emergency stops and computer hardware and for example environmental testing. We only need to pull out the novel parts and a whole system view.

Historically naval ships are built to naval codes which stem from their commercial equivalents adding in the military delta. With nothing expected from the International Maritime Organisation (IMO) in terms of autonomy legislation until at least 2025 and the Maritime and Coastguard Agency has only just released a workboat code annexe to support the regulation of remote-operated systems less than 24 meters. The RN does not have the luxury of well-defined regulation and has almost by accident become the front line in the regulation space, placing pressure on getting it right.

The challenging bit is the "autonomy delta" Figure 1 shows a simple autonomy system assurance needs to be placed on each area to be able to have an "assured" overall system,

[1] Level 0: No Driving Automation, Level 1: Driver Assistance, Level 2: Partial Driving Automation, Level 3: Conditional Driving Automation, Level 4: High Driving Automation, Level 5: Full Driving Automation (Society of Automotive Engineers, 2021)

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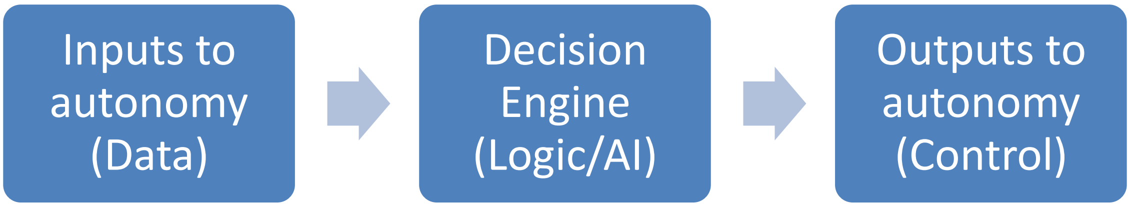


Figure 1- Autonomy System

This paper seeks to look at the decision engine element which in isolation is a dangerous focus as whilst it will assure an output, it is based on controlled inputs which may not replicate the real world. Equally these outputs will be used within a system but might not have the effect that is expected when integrated into a machinery system. A whole system view is critical to having a robustly assured solution, the sensors feeding into the decision engine are as important to fully understand, as the autonomy itself. This drives a significant amount of work in developing an understanding of the inputs before any relevant work can be done in the decision part. Neither box can be fully understood without an awareness of the other e.g. the decision drives a sensor demand. We often expect our operators to know or at least acknowledge if a sensor isn't reading right, so how do we have a computer that can do the same and then also deal with it?

You could run the platform in incrementally challenging operating environments over an extended period with people either, onboard or readily able to prevent a collision. However as the complexity of the systems increases, the rate of technology adoption increases, and the edge cases are realised this will fall over as an unsustainable proposition. This is where computer-based models and synthetics can help us.

Even significant other programmes are grappling with the problem, The Nippon Foundation MEGURI2040 Fully Autonomous Ship Program whilst ambitiously set a practical implementation by 2025 they also state 'there has been almost no development to date in the field of fully autonomous navigation for seagoing vessels.' (The Nippon Foundation, 2024). The Yara Birkeland programme is also not going as quickly as planned 'Yara Birkeland completed its first-fully autonomous voyage, under human supervision, from Yara Porsgrunn to a container terminal in Brevik in March 2023. However, owing to regulatory issues, the ship currently operates with a crew of three onboard who supervise and monitor the ship for safety reasons.' People are being removed from the platform but to undertake remote positions (Yara, 2024).

## 4. How computer modelling can be used

Computer modelling allows us to test software without having to install it into a wider system. As long as its context and limitations are known then this is a robust way of providing evidence to regulators. Some of the biggest benefits of this can be found in the ability to test edge cases and also the ability to do 1000s of runs faster than real time.

There is already the ability to test autonomy in real time, this is a service currently offered by BMT using the Marine Autonomous Surface Ships Synthetic Environment Assurance System (MASS SEAS) (BMT, 2024) but it could be seen as falling short, the REMBRANDT system SEAS employs is primarily designed to train human seafarers. Humans interpret the environment and take actions to influence the ship, the training simulators need to be representative of the real world in terms of time, there is an opportunity to model faster when we remove the need for human interaction, ultimately the aim of higher levels of automation.

Modelling faster than real time will enable the generation of significantly more data points in a time that is palatable to the demand of autonomy, it will enable the running of all the 'normal' cases but also the more novel edge cases. A V-model verification demands the requirements up front, compliance with the International Regulations for the Prevention of Collision at Sea (IRPCS) or 'COLREGs' would be a requirement but the measurement against this is incredibly challenging. Whilst measurable with several scenarios in a real time simulator there would be limited confidence in the edge cases. It also presents a challenge for real world validation as it is very unlikely that the same scenario can be replicated, getting the same targets, in the same location, in a

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similar operating environment, especially when compared to CFD validation where this is normally relatively easily replicated in a wind tunnel or piping system. Significant numbers of runs will also allow the implementation of other variables such as sensor degradation, increased sensor uncertainty and the failure of certain sensors all of which would be informed by the sensor work.

### *4.1. COLREGs*

One of the main aims of autonomous navigation is compliance with COLREGs which defines how to prevent collisions with other ships as well as the means to do this. It states provisions e.g. the display of day shapes to support the decision making of other ships. In a fully autonomous ship, all of these rules will need to be applied by the machine and therefore scenarios where each of these rules is tested will be needed. Often the ‘perfect’ scenario is used, for example in Figure 3 a crossing scenario is shown where vessel B is the stand on and vessel A gives way, this could be one run in an autonomy validation however in the real world it could look more like Figure 2 or anything in-between this presents a challenge when later validating the simulation if only certain situations are simulated.

(International Maritime Organisation, 1972)

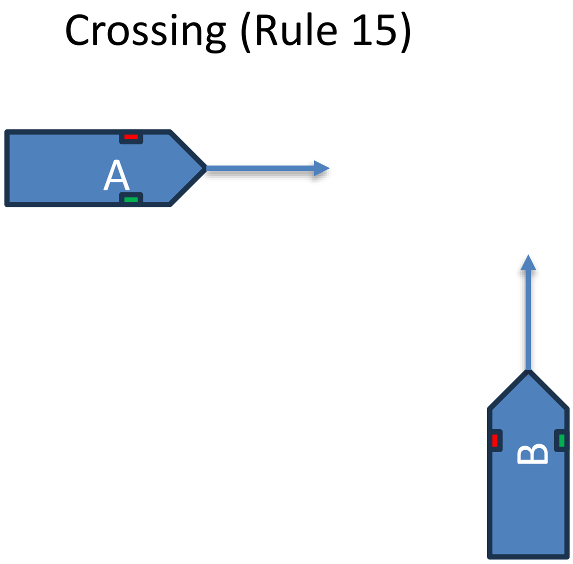


Figure 3- Simple Crossing scenario

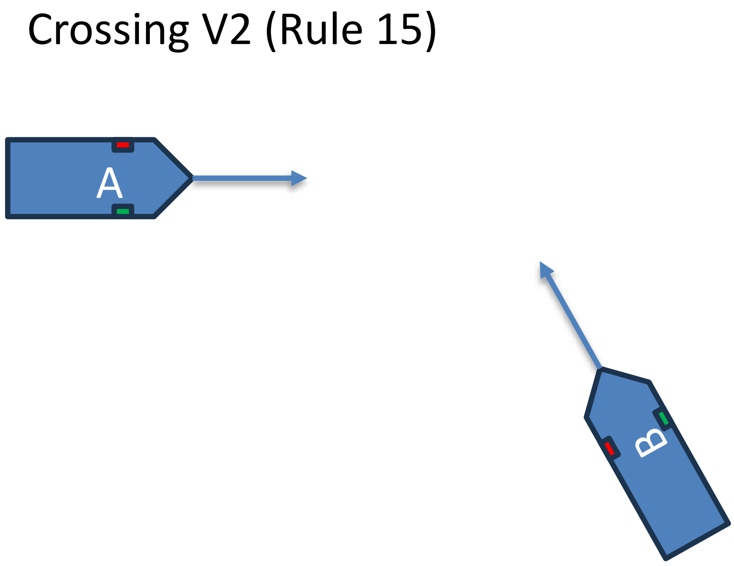


Figure 2- Variation on a simple crossing scenario

### *4.2. To what standard?*

Watchkeepers who are entrusted to operate ships in complex water spaces are trained over a number of years gaining experience while completing numerous training courses. The proposal of navigation autonomy means there is an expectation that you can remove that person and put in a computer. However, there is an expectation that humans are not perfect, so does autonomy need to be?

A term often used is to ‘be at least as good as a mariner’, ships are normally operated by Officers of the watch who over 3 years learn how to operate ships before passing an exam with the relevant administration e.g. MCA before proceeding to sea. However, they are still accompanied on board by other more senior officers of the watch, a chief officer and a master. Complex water navigation is normally undertaken by the chief officer or the master these have more experience and have completed additional exams respectively Figure 4 shows this progression (Warsash Maritime Academy, 2024).

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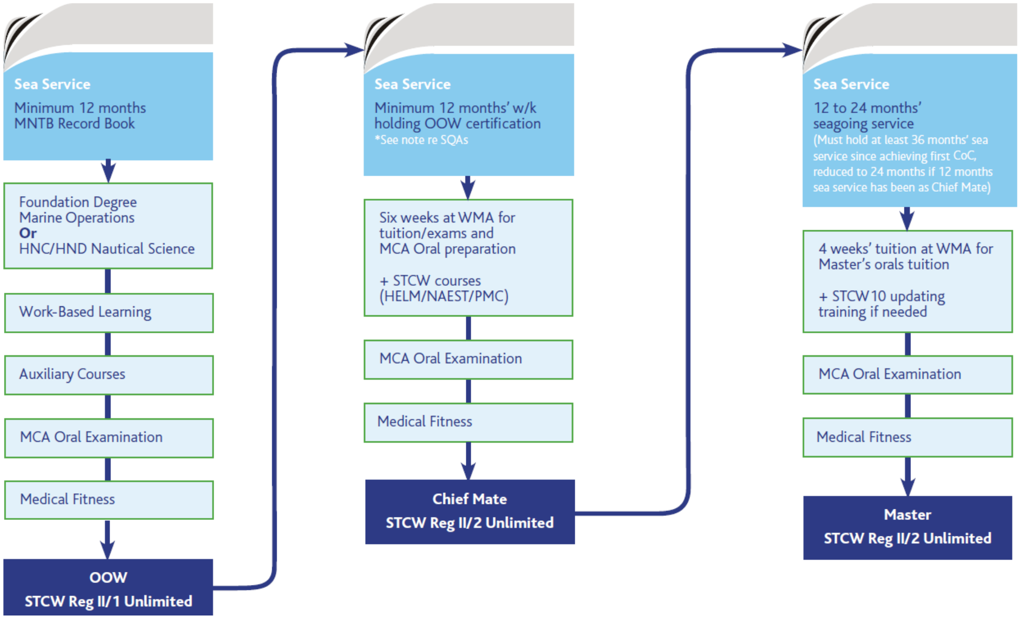

Figure 4- Progression Chart for Officer Cadet Routes (Warsash Maritime Academy, 2024).

The real challenge is that we would expect autonomy to be at least as good as a master, which is almost impossible to measure. The European Maritime Safety Agency (EMSA) issues an annual report each year on safety incidents on EU-flagged ships or incidents occurring in EU waters. The largest number of incidents occur in 'internal waters' which is considered the more complex operating space, 21% of maritime incidents in 2014-2022 were collisions with a range of root causes. Some are attributed to mechanical defects, whilst some are down to operator error (European Maritime Safety Agency, 2023) for example, the collision between Scot Explore and Happy Falcon on 24 October 2023 (Marine Accident Investigation Branch, 2024).

There is an expectation that by using artificial intelligence the software will improve as it learns, however, there is always a chance that it will perform to a lower standard than its initial installation point. Once a Master passes their certificate of competency there are no further checks on their ability to apply IRPCS. The MOD are different in that RN watchkeepers complete IRPCS tests at regular intervals. Given the reliance on software, it could be seen as reasonable that a periodic sample of the software is taken, which could be based on risk, this is then tested in the already validated synthetic environment with the expectation that it would continue to pass the runs.

For defence, a risk balance approach could unlock some of this challenge, currently ships in the MOD undergo a HAZID such that the level of risk the ship has can be held at the correct levels. There are many example risk matrices available, but the principle remains the same the combination of likelihood and consequence enables an understanding of a risk level and if it is tolerable for example Figure 5. Quantitative matrices allow mathematical calculations to influence the score e.g. a system might fail $1x10^{-6}$ times in a lifetime (Ministry of Defence, 2024)

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| | Consequence | | | | |
|---|---|---|---|---|---|
| Likelihood | Negligible 1 | Minor 2 | Moderate 3 | Major 4 | Catastrophic 5 |
| 5 Almost certain | Moderate 5 | High 10 | Extreme 15 | Extreme 20 | Extreme 25 |
| 4 Likely | Moderate 4 | High 8 | High 12 | Extreme 16 | Extreme 20 |
| 3 Possible | Low 3 | Moderate 6 | High 9 | High 12 | Extreme 15 |
| 2 Unlikely | Low 2 | Moderate 4 | Moderate 6 | High 8 | High 10 |
| 1 Rare | Low 1 | Low 2 | Low 3 | Moderate 4 | Moderate 5 |

Figure 5- Example risk matrix (Kaya, Gulsum, 2018)

If the likelihood of collision could be understood via validated synthetic assurance and compared against severity, then a risk holding level can be obtained. It might be a case that results in collision occurs $1x10^{-6}$ times and the expected outcome in a 1-10 person fatality using the Common Risk Classification Matrix used by DE&S this would result in a Category C risk which can be considered tolerable if As Low As Reasonably Practicable (ALARP). It might be that additional mitigation is required in the early stages to make the risk tolerable, but the aim would be to bring the likelihood down to such a level that it can be held normally.

Using computer modelling is collecting a series of measurements generated from a digital model, the validation is comparing these with real-world measurements. There is a lot of measuring and therefore a good understanding of uncertainty is needed in terms of occurrence and magnitude. Given the current lack of defined standards to enable the autonomy software and the synthetic assurance system the software can be tested with, the use of claim argument and evidence will allow regulators to make a judgement based on well-presented evidence to make a decision. This will then enable understanding to grow until such time rules and legislation can be developed to be able to simply generate the required evidence in a known methodology. To ensure a robust case can be submitted there needs to be an element of geographic diversity in the testing. There is a need to operate the platform synthetically in a realistic validation environment e.g. the Solent. However, this only proves the platform can perform in this water space. Expanding the synthetic testing envelope to explore differing operating environments including location, changes in other vessels and weather is fundamental to understanding the actual performance level. A significant element of this is changing the sensor performance not only relative to the weather condition but also factoring in general degradation and lower than expected performance or even total loss.

Whilst currently there is aspiration for peacetime operation of these platforms and therefore compliance with commercial rules of the road is required, there will be times such as being in a task group or possibly times of War when the use case will change. This will mean that operating in a COLREG compliant way is no longer the goal and operational advantage is the key driver. This ‘Wartonomy’ function is beyond what will be offered by the commercial sector and will require a deep technical understanding of both performance and limitations to understand how the system will deal with these situations, these are much harder to validate in the real world beyond that of a normal task group or operational experimentation.

### *4.3. Data Points*

A number of data points need to be collated within the simulation and the real-world validation testing. This will enable the validation and enable the levels of uncertainty to be understood. This is data that should be collated on the autonomous vessel but as much as possible should be collated from the target vessels. Table 1 gives an example of several data points but this list is unlikely to be exhaustive. Targets within the real world are expected to be a challenge, in the simulation they will be pre-defined, however, when trying to relate to a real world situation understanding their size, aspect and speed may be more challenging with a lower fidelity sensor suite.

Table 1- Data points

| **Data Point** | **Sensor example** |
|---|---|
| Freedoms of movement (roll, pitch, sway, surge, heave and yaw) | Accelerometer |
| Speed through the water | Speed log |
| Speed over the ground | GPS |
| Heading | Directional GPS |
| Position | GPS, Inertial system |
| Time | |
| Tide | Predicted tide data, pressure and actual tide data. |
| Weather | |
| Sea State | Wave buoy or equivalent ship sensors. |
| Optical image | Electro-optics, infrared |
| Radar tracks | Radar |
| Water depth | Echosounder |
| AIS | AIS transceiver |

All of the above sensors have a level of uncertainty, challenges are accuracy and repeatability that will all need to be understood and factored in both in terms of real-world measurement and simulated measurements.

### *4.4. Validation*

A computer model is useless unless validated, there are a couple of areas that require validation some are well trodden, and others are new. The Society for Computer Simulation (SCS) have been the thought leaders in the validation of computer modelling. They have a few definitions that are still relevant today:

‘**Model Verification**: Substantiation that a computerized model represents a conceptual model within specified limits of accuracy.
**Model Validation:** Substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model.’

(Oberkampf and Trucano, 2002)

What is easy to observe is that the validation needs to meet the intended requirements which need to be carefully defined beforehand, referring to the need buy in from the relevant stakeholders early, ensuring both the modelling is robust and valid but not excessive.

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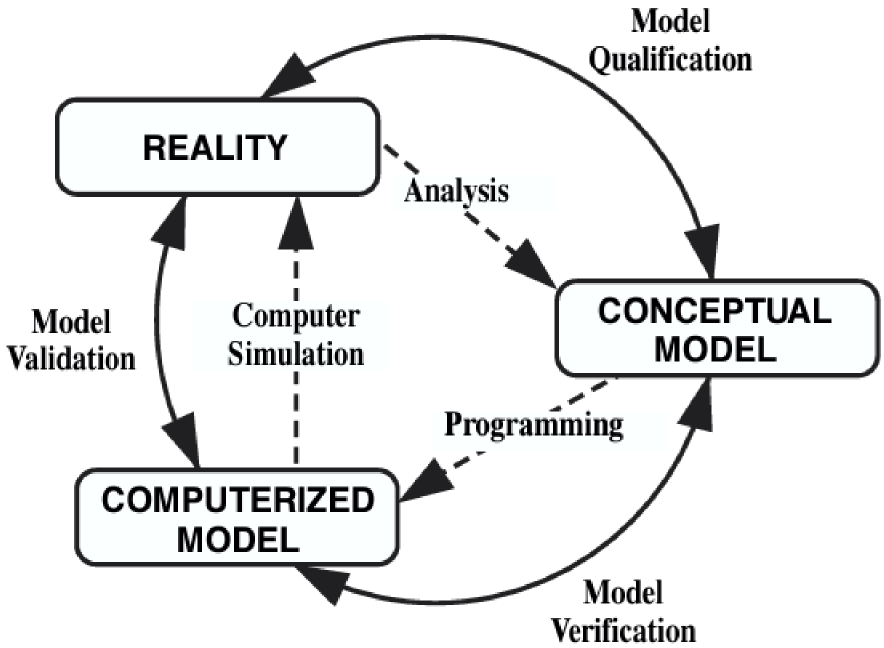


Figure 6- Phases of Modelling and Simulation and the Role of V&V

*4.4.1. Simulation*

The simulator used for the test runs needs to be assured, repeatable and accurate. Simulators are already used for the training of seafarers (Maritime and Coastguard Agency, 2020). The Standards of Training, Certification and Watchkeeping (STCW) gives guidance regarding the use of simulators. DNV-GL provide certification for simulators. One of the challenges of using simulation is the trust in the outputs, there needs to be a robust level of validation and assurance that the models are correct.

There are many classes of bridge simulators that can be used for training defined in Table 2, only class A or B will likely have enough functionality to test autonomous systems fully. There will be elements of the standard that might not be applicable due to the nature of the use case, this will likely be around the hardware in terms of bridge configuration (DNV-GL, 2023).

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Table 2- Simulator classes for the function area bridge operation

| Simulator Class | Description |
|---|---|
| Class A (NAV) | A full mission simulator capable of simulating a total shipboard bridge operation situation, including the capability for advanced manoeuvring in restricted waterways. |
| Class B (NAV) | A multitask simulator capable of simulating a total shipboard bridge operation situation but excluding the capability for advanced manoeuvring in restricted waterways. |
| Class C (NAV) | A limited task simulator capable of simulating a shipboard bridge operation situation for limited (instrumentation or blind) navigation and collision avoidance. |
| Class D (NAV) | A cloud based distant learning simulator capable of simulating a shipboard bridge operation for training through a remote desktop solution by enabling physical and operational realism through virtual reality. |
| Class S (NAV) | A special tasks simulator capable of simulating the operation and/or maintenance of particular bridge instruments, and/or defined navigation/manoeuvring scenarios |

DNV has a recommended practice that directs the requirements for the validation of simulation models. This varies depending on the type of simulation used which is vast and a subject in its own right. It focuses on a risk-based assurance approach whereby risk is defined as the effect of uncertainty on objectives, requiring the uncertainty to be known. A lot of the uncertainty can be understood by knowing how the model was built. This places a lot of the assurance at the front end of the processes before any software can even be tested and there is currently no trusted method for quantifying the uncertainty in simulation models. However, we can make a good assessment by understanding the body of evidence presented to us. For example, the physical ship model can be measured against the real platform placing a relatively low risk in this space if the computer measurements can present a low uncertainty as well as the real-world measurements.

This qualitative assurance method requires a strong body of evidence for each element of the model be that the environment, ship or the physics before any use of the unknown ‘autonomy’ element can be applied. Ensuring that you’re able to provide a robust validated and high confidence simulation facility to the regulator is a key first stage to synthetic assurance of autonomy. (DNV-GL, 2021).

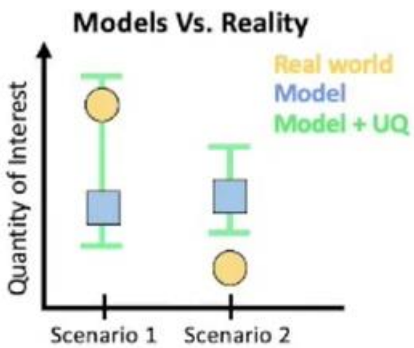


Figure 7- Models vs reality[2] (NASA, 2023)

Figure 7 shows that in scenario 1 there is a difference between the real world and the model the uncertainty covers that and therefore the limitations are known, when compared to scenario 2 where the real world and the model still don’t match but more importantly the uncertainty also doesn’t overlap meaning that the model is essentially useless.

One of the challenges that will face simulation is like that of CFD around mesh size or the level of detail, too much detail and the computer power required makes it disproportionate and expensive, too little and the data collected isn’t good enough to provide a robust body of evidence. This is common again in CFD where two mesh sizes are used to aid the compute demand vs detail required. One way to aid the introduction of uncertainty is to complete runs of scenarios a number of times such that a histogram of data can be generated and not only the average results taken but also the extremes are integrated.

[2] UQ= Uncertainty Quantification

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*4.4.2. Modelling*

Taking the benefit of 1000's of runs there is an opportunity that the modelling can be validated with relative ease. Placing the software on representative scale models if considered especially risky or on full scale prototypes in controlled water targets and scenarios of opportunity can be taken to validate the model. Software that has been tested with a computer model that isn't validated cannot be trusted as whilst it might have performed well in the synthetic environment there is no proof that this is representative of the real world.

The body of evidence generated through the validation coupled with the simulated runs will enable a suitable and safe operating envelope to be established. For the testing of the system on a ship, there will need to be robust safety measures in place and a safety case develop.The pathway could take all of the items in Figure 8 or chose the appropriate starting point depending on confidence.

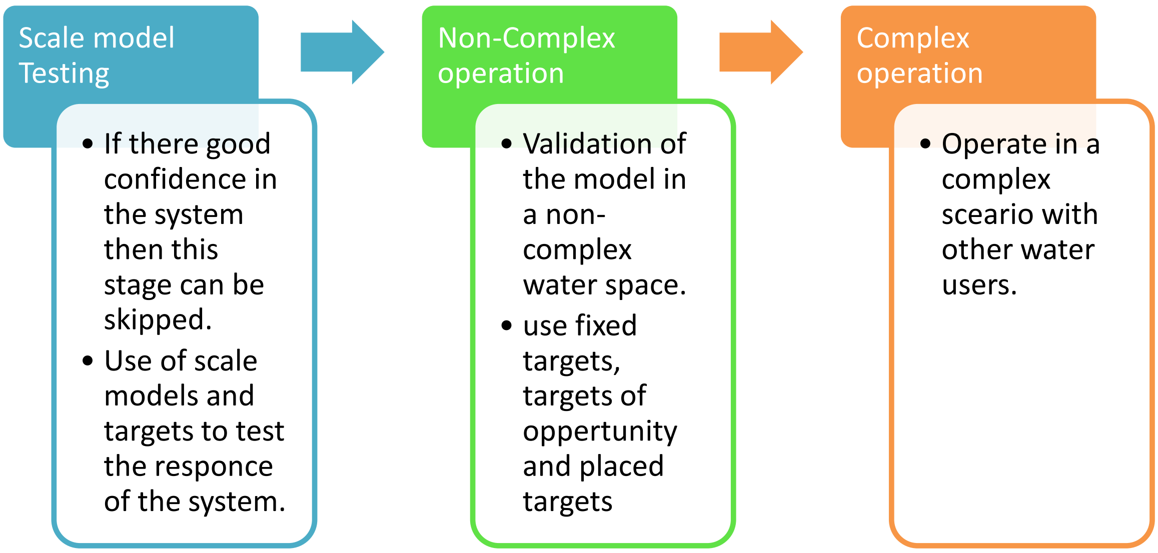


Figure 8- Testing areas

If scale model testing is planned, it is fundamental that the simulation testing of the same environment is conducted to support the validation. Equally, the use of scaling introduces another element of uncertainty into the validation, however, this might be required to reduce the risk to a tolerable level.

In the full-scale testing stages, a significant amount of data can be recorded and compared against the modelled scenarios to understand the model's accuracy. Data collection for validation is key to enabling software to be validated and the methodology for collecting the data needs to be established with a clear understanding of the measurement uncertainty together with the context. This is likely to result in significant data being collated concurrently.

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## 5. Conclusions

Full autonomy is likely to come and whilst currently there is a human in the loop, there is a level of attribution and control from the human operator, albeit remote and challenging. Passing this trust to a machine giving full autonomy will move the onus from the quality of training and experience to the equipment, putting regulators in a new and challenging place. The use of synthetic assurance offers a chance to test and collect data across a large number of cases including those edge cases that don't want to be tested in the real world. However, the data is only as good as the system that generated it. Validation is hard especially when so much work has to go into the system doing the modelling in the first place. Some lessons can be taken forward to ensure good stakeholder engagement upfront so everyone has a clear understanding of the plan and data to be collated allowing later integration. There is then the challenge of what is good enough especially when factoring in a changeable system. The use of tolerable risk is probably a good route to go down certainly for military applications but moving this to a commercial domain might be more challenging.

It will be easy for people to become complacent with the technology and forget its fallibility, reversionary methods of operation will need to be assured as much as the autonomy itself, this includes the impact on the human operators who suddenly find themselves in an unknown water space with an emergency on their hands but no or little contexts building up to it.

Using well evidenced synthetic assurance that has been validated by a number of runs in the real world to provide enough confidence of fit will enable a likelihood of collision to be understood, this can then be applied to a risk matric. There is then a choice of further mitigation perhaps by operational limitations or acceptance. There is an ongoing challenge with how we manage changing software, it might be that in the early stages an instantiation is tested on a 3 monthly basis until confidence is such that the timeline can be extended. We know the model will be wrong, but we need to understand the uncertainty such that we can make an informed decision on if it is acceptable or not. Autonomy will only be possible with the acceptance of synthetic assurance and therefore its development is as important as the autonomy software itself.

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