Discrete Event Simulation: providing a unique modelling solution for complex defence planning

Stephanie Knight[1] & Jake Rigby[1]*

[1] *BMT, UK*
* Corresponding Author. Email: jake.rigby@bmtglobal.com

Synopsis

Critical decisions are being made today which will shape the delivery of Navy capability for decades. At the defence programme level, design and planning decisions are already challenging and complex. At the enterprise level, these programmes must be considered collectively as decisions are made for the future of facility, infrastructure, workforce, crewing, and supply chain requirements. The growing complexity of these systems provides the opportunity for new analytical tools to support the design and planning choices being made. In an increasingly digital world, it is vital to embrace new modelling and simulation tools to inform capability sustainment, acquisition, and support system decision making. One modelling and simulation technique growing in popularity in defence is Discrete Event Simulation (DES).

DES models consider a system as a discrete collection of events, with each event having some defined effect on the rest of the system. The individual processes comprising a system can be defined in terms of their system trigger and impact, and resource requirements. Complex and integrated problems can then be split into simplified modules. The configuration of these modules is analysed and optimised, and key dependencies between modules are clearly defined. DES has a range of benefits over continuous simulation models including speed and configurability. Since the system is defined from the bottom up, changes to low level processes can be trialled rapidly and without having to reconfigure high level logic.

The significance of the approach explored in this paper is that Navy support systems are modelled together as a holistic enterprise, yielding powerful insights into the dynamics caused by the interplay between these systems. Extant modelling approaches are limited by the assumption that system interdependencies are always adequately met, and so any insights into the cascading effects of constraints on external system bandwidth are lost.

The holistic DES approach examined in this paper provides a superior decision-making support tool, which is already being utilised in the Australian Defence sector and could provide benefits to European Defence communities. DES is ideal for testing trade-off scenarios before they become a costly reality. With this approach, the operation of enterprise level systems spanning decades can be simulated in seconds, providing a valuable insight into how design decisions being made today will impact the capability in the next generation.

Keywords: Simulation; Warship; Technology; Discrete Event

1. Introduction

Critical decisions are being made today which will shape the delivery of Navies' capabilities for decades. At the defence programme level, design and planning decisions are already challenging and complex. At the enterprise level, these programmes must be considered collectively as decisions are made for the future of facility, infrastructure, workforce, crewing, and supply chain requirements. In this paper, we will discuss what it is about these challenges which makes them so complex, and why discrete event simulation is the right tool to capture this complexity in a manageable, and meaningful, way. This paper will use examples from a "fleet support system model". This model, built using the discrete event simulation software FlexSim, has been a decision support tool used by the Royal Australian Navy (RAN) since 2017. Examples taken from this model will be used to demonstrate how this wholistic enterprise modelling approach can deliver value to capability planners and decision makers in a practical way.

Author's Biography

Stephanie Knight is a Simulation and Software engineer in Melbourne, Australia. She has been a core part of the modelling team since 2020, developing discrete event simulation models for both commercial and defence clients, including the fleet support system model described in this paper. Stephanie has a Masters in Mechatronics Engineering from the University of Melbourne.

Jake Rigby is the Research and Development Lead, responsible for the portfolio management of internal research projects in defence. He is a chartered engineer and Member of the Royal Institute of Naval Architects originally training as a Naval Architect specialising in ship signatures before his current role of R&D lead. Jake is also responsible for Academic Engagement at BMT. In recognition of his work to progress Academic Engagement in the maritime sector he was recently awarded the title of Honorary Associate Professor at the University of Exeter, and continues to engage in a range of collaborative research projects.

2. What are the Challenges in Defence Planning?

The life cycle of defence projects, from early strategic and concept planning, to requirements setting and analysis, through to the development or acquisition and delivery of a new defence capability, can span decades. It's only once a new capability has been delivered and is in-service, that any insufficient early life cycle planning horizons begin to manifest as poorer than expected operational performance and availability. Defence projects and defence capability platforms are immensely complex systems-of-systems, with complex requirements/interdependencies, and there are many distinct reasons why planning for the future of these platforms is difficult.

At a high level these challenges are common to all systems engineering problems. In the context of a Navy capability such as a fleet of submarines, there are several specific and topical examples of such systems engineering domain challenges which could be examined. The following discussion will look at two possible examples.

The first example is that requirements for a submarine capability change over time in response to changing geopolitical and technological landscapes. This challenge couldn't have been made clearer to the RAN than in the case of the AUKUS pact, announced on 15 September 2021 (GOV.UK, 2021). The magnitude of the ramifications of this decision on the future Australian submarine capability are wide ranging and difficult to quantify. Yet now that the agreement has been made, decisions on how to bridge the capability gap between the current Collins-class submarines (Figure 1) and the future nuclear submarines must be made in the short term. Should Australia adopt a 'son-of-Collins' solution (ABC, 2022), or purchase nuclear powered submarines from the United States (The Australian, 2022) to fill the gap? A 'son-of-Collins' solution would provide continuity to submariners and the lessons learned from the commissioning of the original Collins-class fleet would be directly relevant, but to what degree would it help the ship building industry, as well as other support industries, to critically avoid a Valley of Death, and could the RAN even viably operate with a third class of submarine?

Figure 1 RAN Collins-class submarine HMAS Rankin north of Darwin during an exercise, September 5, 2021
Image reproduced from Business Insider (2021)

Just as the AUKUS agreement was based on the need to meet a fundamental change in operational requirements, capability planners and decision makers in the Future Submarine Program will need to continue to maintain and manage changing and interconnected system requirements as the nuclear submarines move from the concept stage through to development stage and ultimately to steady state operations. One of the most important domains for requirements setting and analysis is the support systems and industries driving the sustainment and operations of the submarines. From supply chain to facilities and infrastructure, to the training and attrition of sailors and submariners, to maintenance workforce planning, the challenges are unique, yet enterprise level planning decisions demand a unified understanding of the dynamics between these support systems and their requirements.

A model of the demand on support systems would assist in the derivation of these requirements and understand how they change over time. When considering the capability landscape in undersea warfare in Australia in the late

2030s and beyond, the ability to generate insights into any emergent impacts to fleet-wide availability, that might arise from failing to meet minimum support system performance requirements, would be critical in decision-making for associated cost versus capability trade-offs. Insights would be needed into the requirements for additional berths, docks, major equipment, and major supply chains for additional and new systems associated with the nuclear platforms, as well as insights into the increase to the size of the submariner, and associated industry workforce. There would be an extent to which the existing Collins-class submarine support system infrastructure would be able to be leveraged and pooled to provide support to the future RAN nuclear submarine fleet. Conversely, there would be an extent to which aspects of either fleet's support system would need to be specialised.

Staying in the submarine support system domain, a distinct example of a systems engineering challenge for capability planning in Defence is that these support systems are highly interdependent, with relationships between constituent components creating feedback loops which are difficult to predict, and that compound and cascade any performance impacts throughout the enterprise. As a result, the relationships between system performance, and overarching fleet-wide availability, are non-linear, and insights into their nature are not immediately intuitive. Performance limitations from one component of the support system can create limitations in organisationally distinct and seemingly unrelated components elsewhere in the enterprise.

An example of this is the cascading effects on a capability platform due to a constrained maintenance workforce. If a maintenance workforce is over utilised, this will cause delays in a vessel's planned maintenance schedule, and the maintenance backlog will grow. If the maintenance backlog is allowed to continue to grow over several years, this will lead to prolonged periods where the vessel should have been operational, but to meet seaworthiness requirements, is instead required to undergo out of cycle maintenance. This, in turn, has a negative effect on the experience of the crew, who will spend more time onshore. It also impacts the ability for Navy to maintain a continuous shipbuilding program, as docking facilities will be increasingly utilised for the maintenance of aging vessels. In Australia, maintaining the integrity of the continuous shipbuilding program is critical for avoiding the industry Valley of Death. And so, at this point, what began as an over utilised maintenance workforce in the short term, in the long term has turned into a compounding problem, where the maintenance workforce is over utilised and therefore also to contributing to its own long-term skills shortage. In a problem space with this level of interconnectedness, modelling is necessary to overcome this complexity and generate meaningful insights.

In this section we have discussed two examples of how complexity can arise in defence capability planning. The first example highlighted the fact that requirements change over time, and that systems engineering best practices must be applied to ensure that systems are robust to these changes. The second example looked at how the interconnected nature of subsystems in an enterprise can over time contribute to performance limitations in ways which might be difficult to predict. These examples both highlight the complexity of the challenge facing the RAN and navies around the globe, and a wholistic enterprise modelling approach is necessary to overcome this complexity and generate meaningful insights to support enterprise level decision making.

3. What Is Discrete Event Simulation?

Discrete Event Simulation (DES or also known as Discrete Event Modelling (DEM)) is the technique of representing a system as a sequence of events where each event occurs at a particular instant in time and represents a change in the overall state of the system being modelled. This simplification of a process is used to better understand and model performance statistics for time and resource critical operations. The individual processes that comprise a system can each be defined in terms of their system impact, resource requirements, and trigger, which may be scheduled, random, or in response to another system event. Once these constituent parts have been defined, they can be combined within the model to recreate the system from the ground up.

Advantages of DES are its speed and configurability. Unlike continuous simulation models, in which each time slice is considered equally, DES can accelerate results considerably by only considering events which alter the state of the system. For example, DES models can simulate the entire lifecycle of a vessel class, from build, to

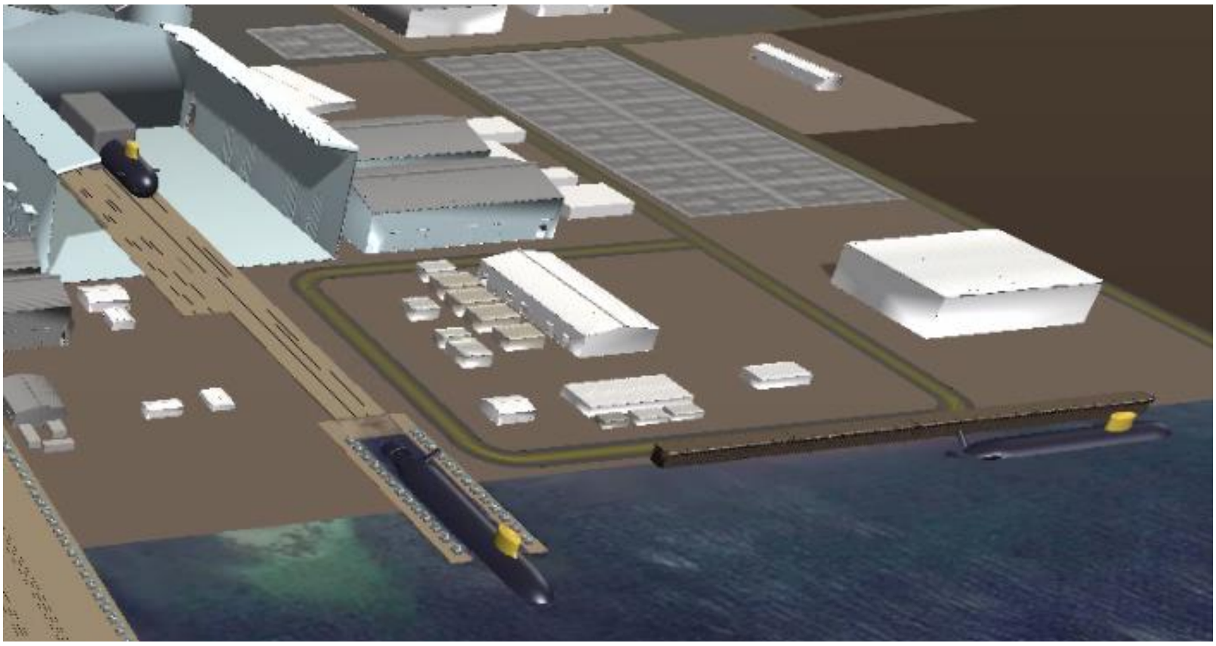

Figure 2 FlexSim 3D Model Floor Example

commission, to life of type extension, to decommission, all within a matter of seconds. Additionally, since the system is defined from the bottom up, changes to low level processes can be trialled virtually instantly, without having to reconfigure high level logic. This modelling approach contrasts with models built using spreadsheets, for example, which can often end up being a logical black box and are difficult to interrogate or reconfigure.

Another key advantage of DES is the ability to visualise the processes and dynamics which are being simulated. This not only aids model developers in the construction and validation of the model and model behaviour but is also a valuable stakeholder engagement tool. Visualisations allow stakeholders to understand and establish a level of confidence in the model, and the advice garnered from model results, which is critical to sound, defensible decision making. There are many popular discrete event simulation software products available on the market, the approach discussed in this paper has been based on a model built in FlexSim, a leading DES software package widely used throughout dozens of commercial industry sectors including manufacturing and production, warehousing, and transportation. Figure 2 shows an example of a visual representations of a ship building yard, which has been modelled in FlexSim in the 3D Model Floor environment.

One of the key challenges common to all model designs is that of scoping the problem. It would be theoretically possible to build a model which captured every single moving part of a system across an entire lifecycle, but realistically this model would be far too difficult to build, and even more difficult to maintain. Instead, a successful modelling solution takes a considered approach to which subsystems are most relevant, what data is readily available, and what problems the customer is most interested in understanding, in order to design, build, and maintain the model. For example, a particular sub process with limited data and high complexity might take up 40% of the total modelling time due to the complexity of the problem, but have less than 0.1% of an impact on the final result. In this case assumptions can be made and captured in the Master Data and Assumptions List and the 0.1% error recorded instead than looking to solve the problem completely. DES models inherently support this approach due to their modular structure and reliance on process flows and sub process flows. The important thing is to use a sensitivity analysis to understand which aspects really matter and ensure the critical relationships are captured (including operational and or cultural components), additionally any simplifying assumptions must be captured for customer and SQEP review and approval.

Figure 3 shows an example of the Process Flow modelling tool from the “fleet support system model” built using FlexSim. Having visual process flows reinforces the benefits of developing a modularised model and breaking high level routines down into subroutines wherever possible, which is critical when dealing with complex problems at the enterprise level. At this level, the dynamics of the low-level components, for example the allocation of day-to-day activities amongst a maintenance workforce team, are impossible to grasp. Instead, a model might simply consider a maintenance workforce team as a resource “unit”, which can be acquired to do a certain task, then released when the task is complete. This allows capability planners to focus on the high-level modelling objectives, then increase the fidelity of the model only in the areas that require it.

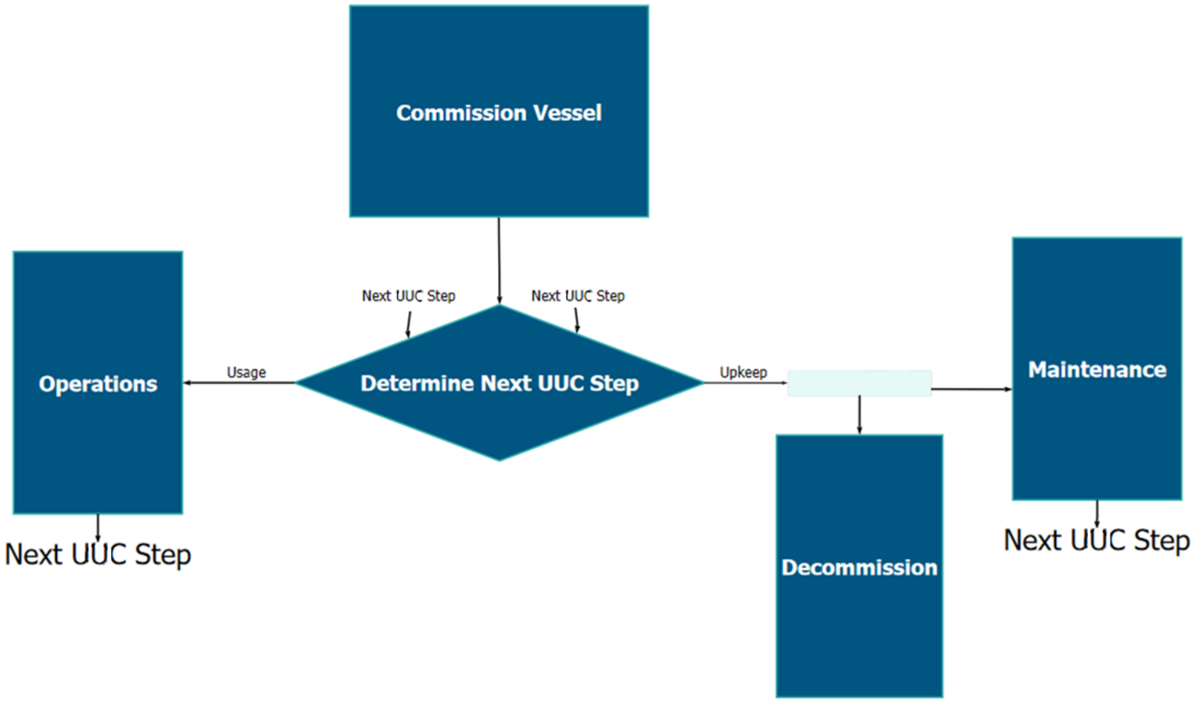

Figure 3 FlexSim Process Flow Example

4. The Wholistic Enterprise Modelling Approach

The fleet support system DES model discussed in this paper is a model composed of several modules which work together to simulate the mission and support systems of a fleet of vessels. The first iteration of the model itself was designed and developed in 2017 for the Future Submarine Program of the RAN. The model has since been expanded in certain areas and refined and refactored as required to suit the needs of the Hobart-class destroyers and the Anzac-class frigates, both also belonging to the RAN. The model has been designed to accommodate multiple classes of vessel in single simulation, and to accommodate vessels transitioning from one class to another via a Life of Type Extension (LOTE) phase (Figure 4 shows an example model Display Output).

In the fleet support system model, each module is responsible for a specific unit or resource. The top-level Vessel Usage and Upkeep module, for instance, tracks each vessel as it progresses through its Usage and Upkeep Cycle (UUC). The primary method of interaction between modules is requests. These represent a requirement from one module which is to be satisfied by another. In general, Operating and Sustainment Support Requests are generated by the vessels in service, and these propagate through the model to generate workforce, supply chain, and facility requirements. For a given UUC to meet desired fleet performance metrics, it is necessary that workforce, supply chain, and facility requirements are satisfied. An example process is a vessel returning from an operation, in need of sustainment. This generates a Sustainment Request input to the Capability Sustainment module and a set of requirements are produced, represented as Workforce Requests, Facility Requests, and Supply Chain Requests. These requests are passed to the relevant modules to be fulfilled.

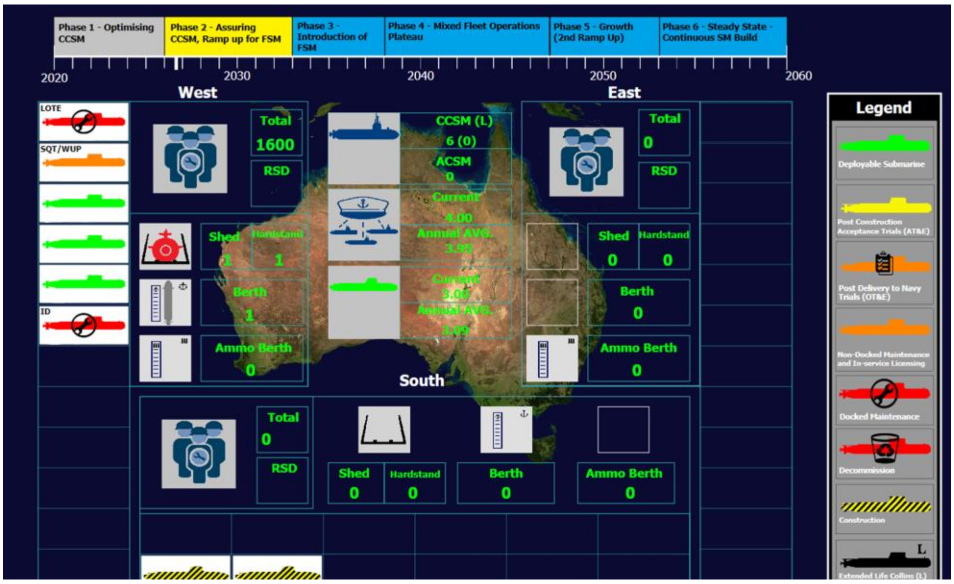

Figure 4 Model Display Output

The model has two modes of operation for managing requests: push and pull. Operating in a pull mode, facilities, supplies, and workforce resources are all assumed to be unconstrained. This allows for the execution of an idealized sequence, in which resource demand can be quantified. Operating in a push mode, the provision of resources is fixed based on the inputs and constraints associated with the support system hypothesis or scenario that is being simulated. This allows for the effectiveness of support system designs and strategies to be evaluated against key performance metrics and other areas of interest (Figure 5).

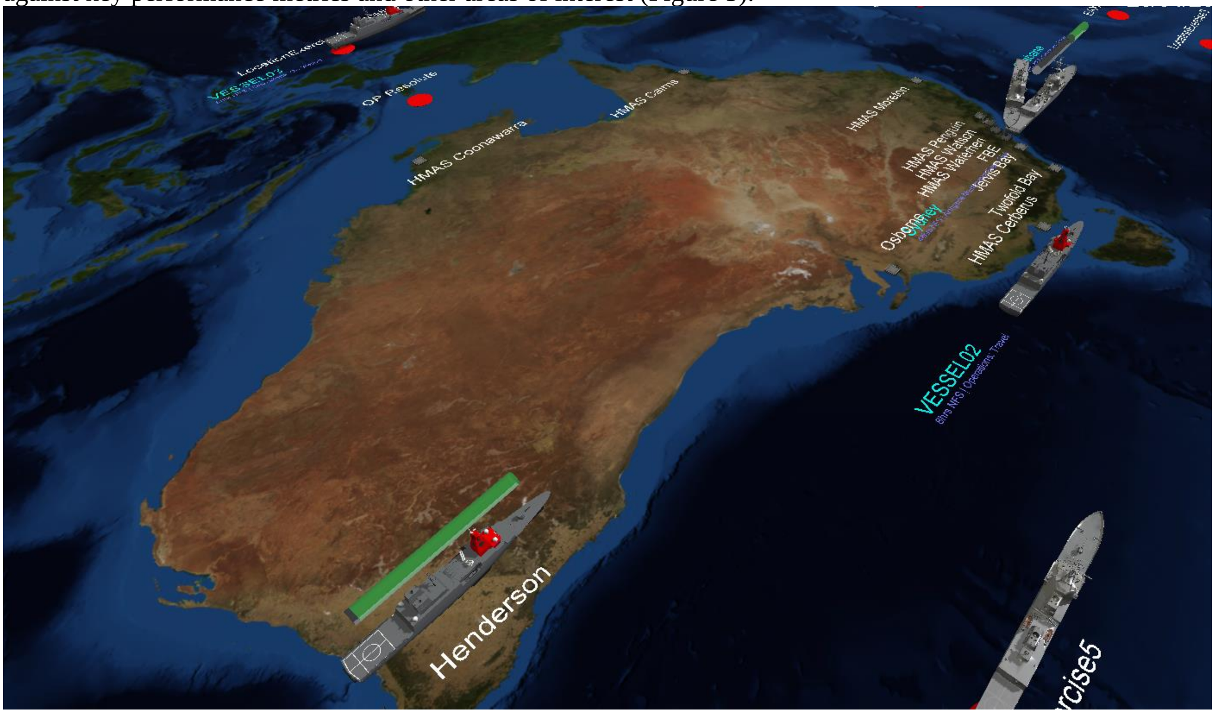

Figure 5 Model Visualisation of Vessels Transiting and Doing Maintenance

Each module has its own independent process flow, but the inputs and outputs of these process flows can interact with other areas of the model. A summary of the purpose of each of the key modules is as follows:

- Vessel Usage and Upkeep: This module tracks the movement of each vessel in the system. Mission execution results in Operating Support Requests, while Replenishment, Maintenance, Assurance (post-maintenance) and Crewing generate Capability Sustainment Requests.

- Capability Sustainment: This module handles the provision of replenishment, assurance, maintenance, and vessel crewing. It generates Workforce Requests for Sailors/Submariners and Maintenance Workers and Workforce Support Requests for required support personnel. Required maintenance facilities are requested through Facility Requests, while consumables, equipment and services are represented by Supply Chain Requests.
- Operational Support Handler: This module is responsible for provisioning mission support to operational vessels. It takes a mission support request and separates it into the required supplies/equipment and workforce. These are requested from other modules through Workforce Support Requests and Supply Chain Requests.
- Workforce Handler: This module is responsible for routing workforce requests. For a given workforce request, the Workforce Handler will determine the appropriate worker resource pool to select from, then generate a Maintenance Workforce Request, Sailor/Submariner Workforce Request, or Other Workforce Request.
- Supply Chain Handler: This module is responsible for satisfying requests for equipment, consumables, or services. It takes a supply chain requirement and generates Equipment Requests, Consumable Requests and External Services Requests. If additional storage is required, this module also generates Facility Requests.
- Facilities: This module tracks facilities relevant to the model. Facilities are any piece of infrastructure required to execute a support system operation. This may be a dock, an office space, warehouse, training simulator, housing etc.

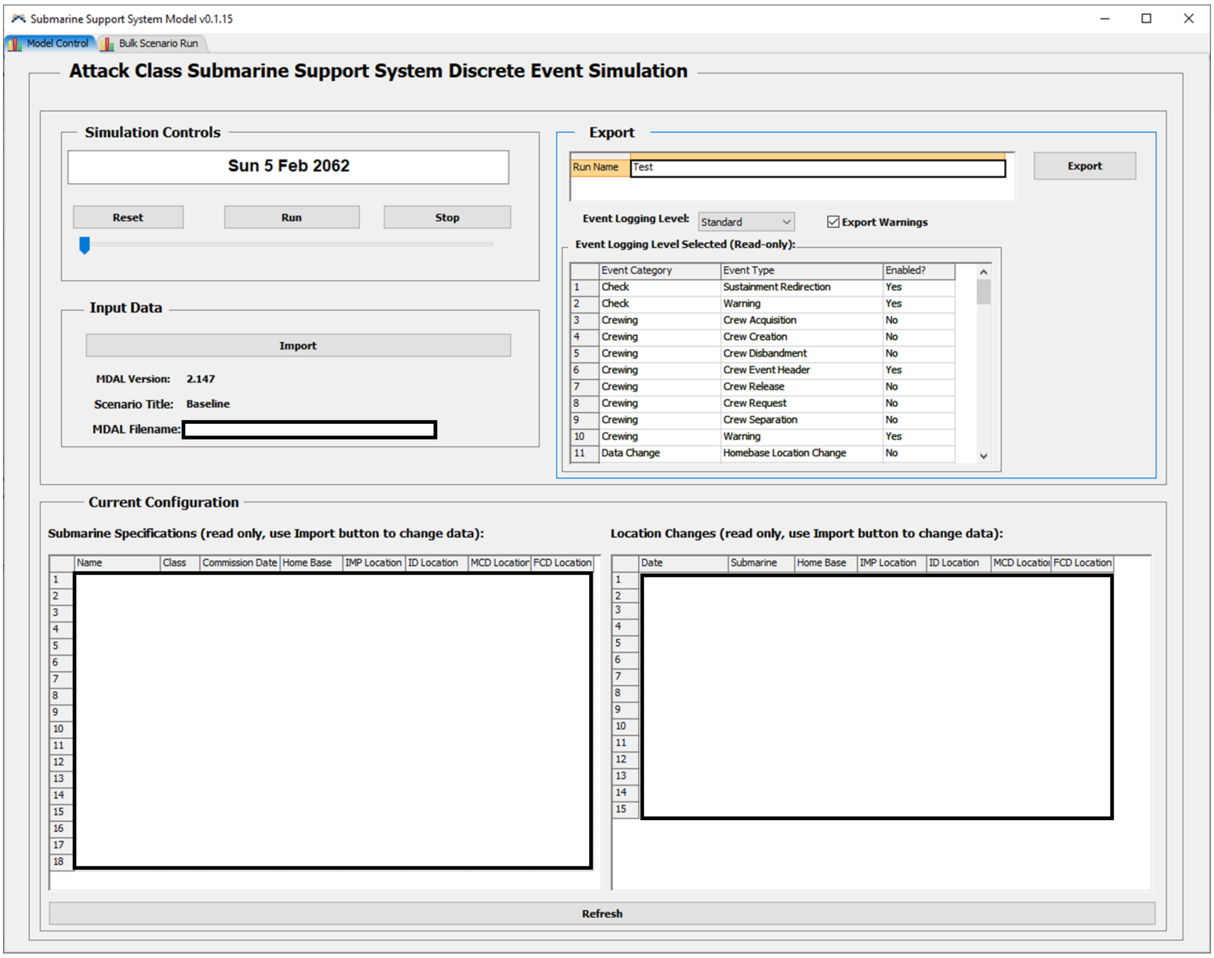

Figure 6 Model Control Dashboard

By being selective about what data and process detail should be included for each subsystem, it becomes increasingly feasible to model enterprise level programmes in a single, manageable model, capable of simulating an entire class lifecycle in minutes, if not seconds. Whereas extant modelling approaches might focus on the dynamics within a single system, with this approach there must always be implicit assumptions that there are no constraints caused from events occurring outside of the system. Similarly, when these models identify system limitations, it can be difficult to translate these into meaningful inputs into other system models.

With the fleet support system model on the other hand, maintenance, replenishment, capability insertions, and deployment for operations can be simulated over the whole class lifecycle. To the extent that data is available, DES modelling can include the requisite fidelity of the support system infrastructure necessary for maintenance, replenishment, and other upkeep activities. These support systems can include sailor/submariner personnel, industry workforce, major facilities and amenities, and key supply chains, including aggregate fleet-wide demand for fuel, rations, ammunition, and other stores. By incorporating these support systems, a variety of use cases can be investigated.

For example, the model can be used to categorise support system infrastructure, supplies, and resources as specialist for classes of vessel or categories of vessel, to generate insights into the minimum requirements to accommodate future Navy fleets. It is also possible to vary the size, location, and configuration of Navy support system infrastructure, supplies, and resources, to generate insights into the impact of specific system performances (e.g., number of berths) on overarching fleet-wide availability and AO (Areas of Operation) presence and generate insights into the potential impact of basing and support infrastructure locations on overarching fleet-wide availability and AO presence. For example, for a given range of scenarios run through the fleet support system model, Figure 7 shows the average number of vessels accruing available days over the decade 2050-2060. Four scenarios were tested to observe the impact of maintenance berth restrictions at a particular location on available days. The results from the model demonstrated that there was little difference between the unrestricted case and the three- and two-berth cases, while reducing capacity to a single maintenance berth causes a noticeable drop in availability.

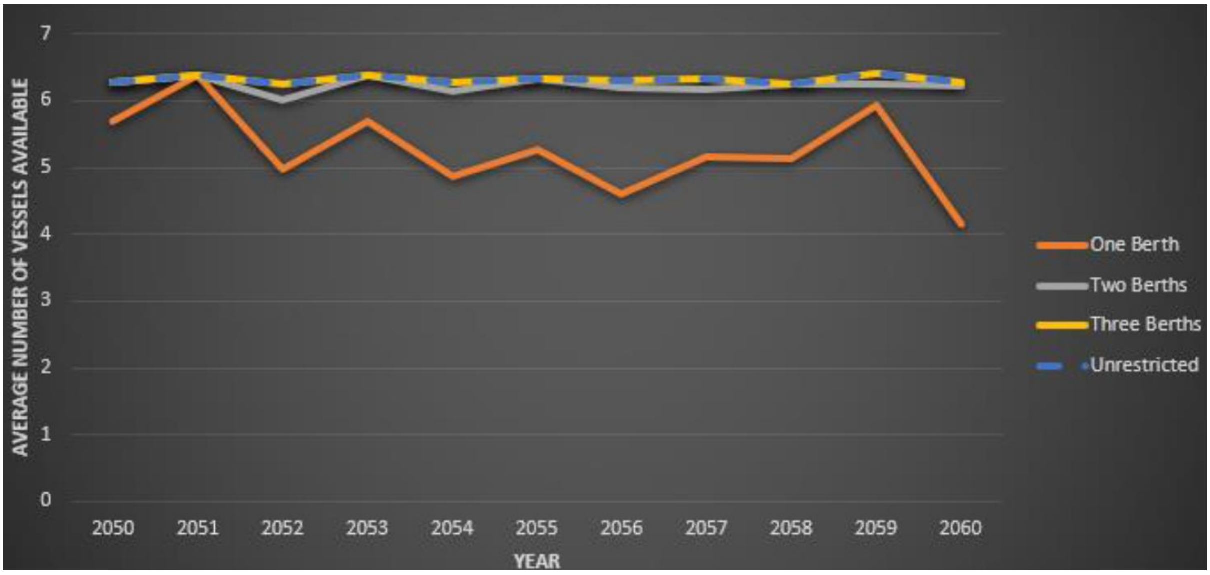

Figure 7 Availability for Different Berth Constraints

Another use case example for the fleet support system model would be that the model can be used to vary the structure and phasing of vessels' UUCs to generate insights into the peaks and troughs of demand on particular support systems, as well as the impact on overarching fleet-wide availability and AO presence (Figure 8). Using the model, it is possible to rapidly simulate hundreds of variations in scenarios, using the above modelling functionality, to understand the sensitivities and drivers of fleet-wide availability and AO presence in each phase of the lifecycle of vessels of interest. For example, for three phasing variations on a scenario using the same fleet wide UUC, there are clearer differences in the degree to which certain scenarios have fluctuating total fleet availability over time. In general, it is desirable for a UUC scheduling solution to have predictable and stable periods of availability to meet OPTEMPO and PERTEMPO requirements. Therefore, this scenario comparison demonstrates a useful insight not only into the performance of certain UUCs, but how that performance changes depending on how the UUC schedule is phased between the vessels in the fleet.

Now that this approach has been tired and tested it would be possible to apply the technique to a new of different fleet. Using the existing fleet support system model as a starting point, it would be possible to set up the model for a new fleet of vessels and begin generating meaningful results within a matter of weeks. The exact time frame required would depend on the data that is available, and to what degree existing model functionality and features need to be adjusted to suit the particularities of the new fleet being modelled. If only minimal data on support systems is available, the model can be operated in pull mode, where a UUC of interest can be simulated, and the corresponding demand on various support systems over time can be produced as an output, rather than supplied as an input constraint.

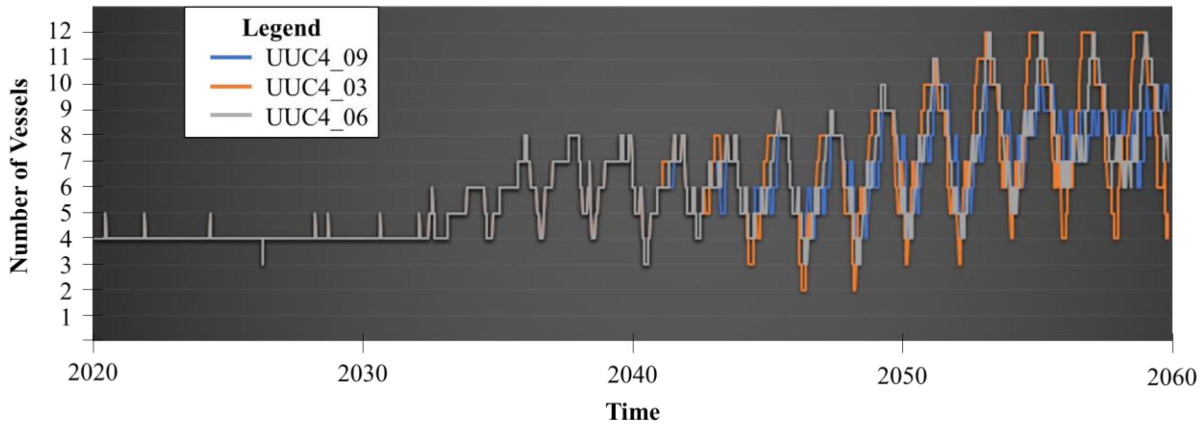

Figure 8 Total Fleet Availability Over Time

5. Conclusions

In summary, Defence operates in a unique and complex environment, creating challenging simulation conditions. The two examples from the RAN highlighted that requirements change over time, and that systems engineering best practices must be applied to ensure that systems are robust to change. The examples additionally highlighted that the interconnected nature of subsystems in an enterprise can over time contribute to performance limitations in ways which might be difficult to predict. To answer complex modern logistics and planning challenges a new toolset is required; a toolset that incorporates a wholistic enterprise modelling approach to overcome complexity and generate meaningful insights. Without this wholistic approach separate system modelling of an inherently system of systems enterprise will lead to duplication of effort and potential errors.

DES can provide the solution with a careful and consolidated approach and has significant benefits over its continuous modelling counterparts. By focusing on the key discrete events, computational speed can be significantly increased allowing for greater options evaluation. It is important to understand that DES is not about the generation of visualisations and graphics, it is the core modelling behind the visualisations that generate the insights. These visualisations do however serve a functional purpose as a validation tool, to ensure the simulation is acting as expected, and as a customer engagement tool.

DES and associated approaches are starting to gain traction in the defence sector, they have been tried and tested in Australia as per the RAN examples highlighted in this paper. Now is the perfect time to explore the wider applications for the technique and put the methodology into practice. The shape of our future Defence capability depends on decisions being made today, therefore it is vital that these decisions are well informed, and based on rigorous and proven models and techniques.

6. Acknowledgements

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