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The Role of System Modelling and Simulation in Royal Australian Navy Capability Management

David Saunders, Moya Tyndall and Tom Whitehouse

DSTO-GD-0244

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Maritime Platforms Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

This report examines the Navy Capability Management process that has evolved from the 1995 review of RAN logistics support and in response to the more-recent Government focus on output based management of ADF assets.

This report seeks to show that capability management should be based on quantitative measures, including the insertion of Measures of Performance and Measures of Effectiveness at appropriate points in the management process. Capability management must also refer to operational requirements and is therefore a requirements-driven process. However, the principal difficulty with this management process is the lack of processes and supporting tools. Modelling and simulation are presented in this report as a means of addressing this difficulty. The main purpose of modelling and simulation is to predict the behaviour of ADF assets (RAN platforms and platform systems) in response to their environments. Environments in this context refer to changing operational requirements and constraints both within and external to the model.

Capability management is a forward-looking, dynamic process and therefore there is a need to develop matching dynamic models as capability management tools. There is no single model that can be generally applied to the many capability management problems however; modelling may be applied effectively to address specific management and technical issues. Models representing the RAN platforms and platform systems, when applied in a simulation process under a range of conditions, can provide useful capability management information. This information may be used to develop appropriate quantitative performance measures.

RELEASE LIMITATION

Approved for public release

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE & TECHNOLOGY ORGANISATION
DSTO

Published by

DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne Victoria 3001 Australia

Telephone: (03) 9626 7000
Fax: (03) 9626 7999

AR-011-483
July 2000

APPROVED FOR PUBLIC RELEASE

The Role of System Modelling and Simulation in Royal Australian Navy Capability Management

Executive Summary

This Report was published previously as a paper in Volume 25 of the Journal of the Australian Naval Institute. It is published as a General Document to achieve wider dissemination of concepts for RAN capability management process; particularly in the application of modelling and simulation.

This Report examines the navy capability management process in mid 1999 and discusses its development from the 1995 review of RAN logistics support and the promulgation of the Chief of Navy Preparedness Directive in 1998.

While capability management is a business process, this Report examines capability management from a systems perspective, stemming from a basic definition of capability stated in terms of the ability of a system to perform specific actions. The management of (military) systems is discussed briefly in terms of hierarchies of systems and the use of Measures of Performance (MOP) and Measures of Effectiveness (MOE) to evaluate the systems in the context of operational requirements imposed on them. The Report discusses the use of modelling and simulation as a way of establishing MOPs and MOEs for military capabilities and providing predictions of system performance in response to operational requirements. Modelling and simulation is seen as one way of managing navy capability as a forward-looking, pro-active process.

The Report briefly discusses how modelling and simulation may be applied to the capability management process and notes that the models must accurately reflect reality, that appropriate data must be collected and that predictions must be thoroughly assessed for accuracy and relevance. The Report argues that modelling and simulation allows capability management decision making to be made on the basis of many scenarios, rather than "simple" historical data. Modelling and simulation therefore allow "discovery" of problems and sensitivities to internal navy processes and external environmental constraints.

The Report briefly reviews modelling and simulation techniques that have the potential to be valuable adjuncts to the RAN capability management process. For example, modelling and simulation have the potential to advise decision making in terms of cost/capability trade-off. Modelling and simulation tools and techniques discussed in this Report include reliability block diagrams, fault trees, multi-criteria decision making, artificial neural networks and knowledge discovery.

Modelling and simulation need to be developed specifically for the RAN capability management processes and the form of the outputs specifically tailored to the navy business process. Modelling and simulation has the potential to allow optimisation of capability delivery across navy's Force Element Groups and to assure materiel readiness for specific operational requirements.

Contents

1. Introduction

Recent reviews of RAN logistics support [1] and RAAF logistics support [2] have highlighted the need to change business processes to meet the preparedness (readiness and sustainability) and supportability requirements of ADF assets in a resource-constrained environment [3]. These reviews have identified that operational requirements must drive the capability management process. More generally, they have identified significant gaps in the process of linking technology, operational requirements and business practices.

The management of RAN assets including human resources is a complex process that, over time, is likely to increase further in its level of complexity. One of the reasons for this increasing complexity is these RAN assets will not be managed individually, but in conjunction with other ADF assets. To achieve effective financial and materiel management, the RAN will need to develop and apply new processes and tools that capture the dynamics of asset management. These new processes and tools will be used to explore how the technical systems of RAN assets and their in-service support systems respond in a changing environment. The environment in this context refers to changing operational requirements and financial, technical and human-resource constraints. For example, how to optimise the allocation of funds so that the required level of capability can be achieved to perform a particular operational requirement. Another example is when to schedule maintenance so that the capability of a platform is maximised during a specified period of time. The need for these tools has been recognised overseas [4] and within the RAN [5, 6]. Significant effort within the RAN has been devoted to defining the framework for a requirements-based asset-management process [5, 6], but this process will also need quantitative methods that can be applied to the dynamic logistics and in-service support environments.

At present there is no accepted definition of capability management. The 1997-1998 Defence Annual Report [7] deals with capability management in a general way:

> *"The Government looks to Defence to provide the widest range of effective military options in any military situation that might arise. The Defence organisation's most important priority therefore is to maintain military capability ready for operations, including, if necessary, for combat. That priority is reflected in Defence's output structure, which identifies the elements of the current capability as the key products provided to the Government."*

In this report, capability is defined as **the ability** of a system to perform specific actions. 'System' is used here as a generic term that describes any system, large or small. Some examples of systems are a Force Element Group (FEG), platform, weapon system, propulsion system, engine and fuel pump. In the Australian Defence Force (ADF) **military capability** is defined in terms *"of two elements - force structure (the number, type and grouping of military units, personnel, equipment and facilities) and the preparedness of that structure for operations"* [8]. An example of how military capability can be managed in an efficient and effective way is given in the Mine Warfare Force Element Group Business Model [9]. This model defines the Mine Warfare FEG capability in terms of materiel support, operations and operational support (Figure 1). The activities or actions that make up this capability include maintenance engineering, training, configuration management, managing preparedness requirements, planning missions, conducting operations and providing port services.

Capability management implies that the ability of a system to perform specific actions needs to be **measured** and compared with a desired measure or benchmark. A **capability gap** exists when there is a deficiency between the measured ability of the system and the desired ability of the system. Simply stated, capability management is the process to identify and address the capability gap within the temporal environment. It is a forward-looking process, particularly when considering a range of possible operational requirements. The main three causes of the capability gap are:

1. changes in operational requirements,
2. changes in the environment, and
3. changes in the performance of the RAN assets.

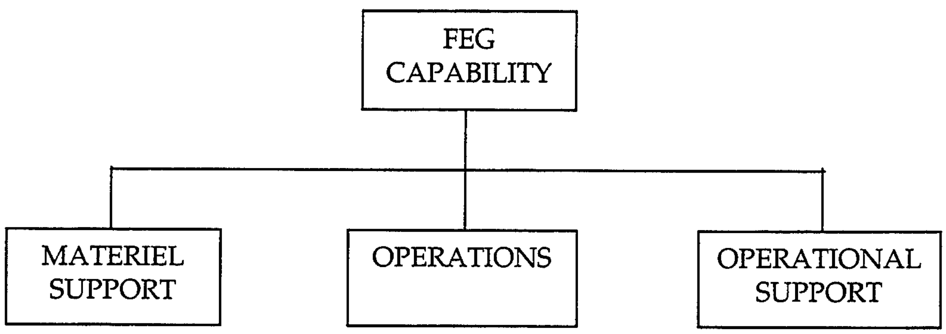

Figure 1: The Mine Warfare Force Element Group Business Model defines capability in terms of materiel support, operations and operational support.

The critical question that should be asked about capability management *is "manage to do what?"*. Capability management needs to be driven by operational requirements, that is, RAN assets respond to requirements to achieve specific outcomes. The dynamic nature of the capability management process will be discussed in this report, and following from this, it will be argued that effective management of RAN capability can only be achieved using quantitative methods. The application of system modelling and simulation will be shown to be one method of quantitative management. Modelling and simulation will allow the generation of "virtual histories" which will allow forward-looking management decisions to be made and which will be directly related to the requirements for the capability. The reality of capability management is that

RAN assets contributing to the capability cannot be placed (and therefore tested) under all possible operational conditions.

There are many modelling and simulation tools currently available that could contribute to the capability management process. Tools based on modelling and simulation need to be initially developed to address specific aspects of the capability management process. This report focuses on the materiel support aspects of the capability management process that are the responsibility of the Class Logistic Offices in Support Command – Navy. For example, modelling and simulation tools could be applied to resources allocation, maintenance scheduling, spares optimisation and obsolescence management. The results from these tools will contribute to the performance and effectiveness evaluations within the capability management process.

In the next section capability management is discussed in terms of systems concepts. This is followed by a discussion of the need for quantitative processes in capability management and how modelling and simulation can be applied to this process. Some of the modelling and simulation techniques that could be used are presented in the next section, followed by a short summary of this report.

2. Capability Management

This section begins with an explanation of system concepts, which is then used to define Measures of Performance (MOP) and Measures of Effectiveness (MOE) in Section 2.2. These concepts are then used in defining the capability management process in Section 2.3.

2.1 Systems Concepts in Capability Management

In this section, the definitions of a 'system' and a 'component' are given. A more detailed examination of these concepts and their application to capability management is given in [10].

The term 'system' is quite loosely applied to many animate and inanimate objects, groups of objects and ideas. The most helpful and general view of a system is that its collective function is only made possible by reaction and interaction of its overall sub-systems and that no individual system can exist without some level of interaction with other systems. Collective, interactive systems themselves are part of some larger system; thus to understand a system requires appropriate boundaries be established which encompass all essential features contributing to the function of the system under study. This view is most instructive when dealing with management and business systems since the function of a business system cannot be assessed without reference to other systems from which it draws and supplies information while (often) imposing mechanisms and constraints on other systems, including those that provide or use information.

"Every system is part of a larger system. It is a system in its own right, and it is also a sub-system of the larger system" [11]. The purpose of the sub-system is to support the larger system in performing a task. *"There are endless chains of systems within systems, in hierarchical relationship to each other"* [11]. The hierarchies of systems for three examples are given in Figures 2a-c. In each of these examples only one system at each level is given. A number of systems at each level can be combined to form the system at the level above. In this report the systems at the lowest level in the systems hierarchy are called 'components'. The analyst who is studying the 'total' system determines the levels that make up the system hierarchy. Therefore, in the examples in Figures 2a-c, the components are transformer, anti-ship missile defence system and fuel pump, respectively.

- Government
- Department of Defence
- Navy
- Force Element Group
- Ship/Submarine
- Anti-Ship Missile Defence System
- Radar
- Transmitter
- Power Source
- Transformer

(a)

- Nation
- Government
- Department of Defence
- Navy
- Force Element Group
- Ship/Submarine
- Anti-Ship Missile Defence System

(b)

- Government
- Department of Defence
- Navy
- Force Element Group
- Ship/Submarine
- Propulsion System
- Engine
- Fuel Pump

(c)

Figure 2: Three Systems Hierarchies examples, adapted from Figure 1 in [11].

2.2 Measures of Effectiveness (MOE) and Measures of Performance (MOP)

Measures of Effectiveness (MOE) and Measures of Performance (MOP) are two sets of metrics that can be used in quantitative management processes. MOEs are measurements of the ability of a system to meet a requirement. Requirements define what a system should be capable of achieving. The effectiveness of a system in supporting the larger system can only be evaluated by determining how well it has helped the larger system meet its requirement [11]. MOPs are measurements of the performance of a system that result from the particular way it is designed. MOPs may be performance characteristics derived from tests and/or trials of systems. Performance characteristics can be measured quantitatively and assessed against a baseline.

To avoid confusion between MOEs and MOPs, it is useful to think of them in terms of the systems hierarchy. It is possible to determine a system's MOPs in isolation but the MOEs of that system cannot be determined unless the requirements of the larger system it supports have been specified. For example, the MOPs of the fuel pump in Figure 2c are inherent to the fuel pump but the engine is the source of the MOEs for the fuel pump. The performance of the fuel pump may satisfy the designers and manufacturers specifications but its effectiveness is determined by how well it supports the engine in the performance of its function. The capacity of the fuel pump to supply fuel to the engine may be too low for the engine's needs for fuel. Similarly, the performance of the engine may satisfy the designers' and manufacturers' specifications but its effectiveness is determined by how well it supports the propulsion system in the performance of its function. This principle continues up the system hierarchy. The ship or submarine is a sub-system of a larger system, the FEG. The ship or submarine is not working alone but in conjunction with other defence assets in the FEG to accomplish the FEG's mission. Therefore, the MOEs of the ship or submarine are determined by the FEG's objectives. These examples illustrate the differences between MOEs and MOPs and these differences are summarised in Figure 3. (Figure 1 in [12]).

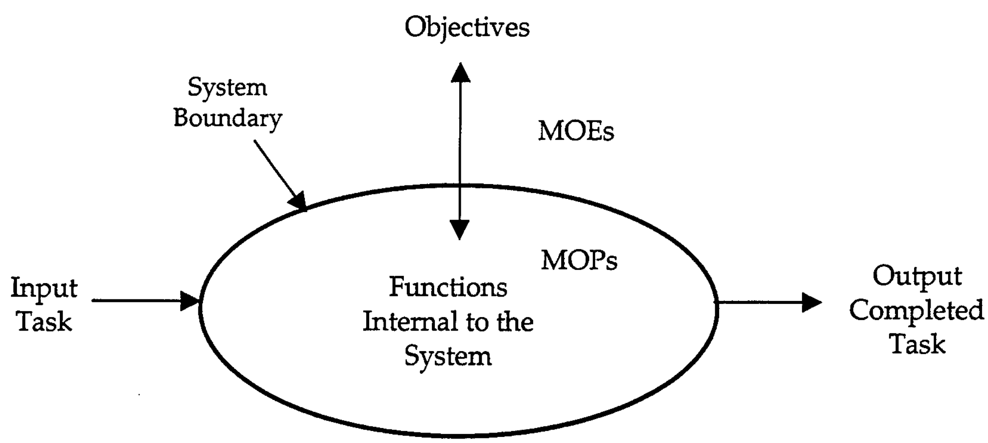

Figure 3: The conceptual difference between MOE and MOP as illustrated in Figure 1 in [12].

2.3 The Capability Management Process

ADF assets, specifically RAN assets, exist to perform specific functions in relation to defence requirements. The capability management process enables RAN assets to achieve specific levels of performance once they have reached the operational phases of their life-cycles[1].

The capability management process is illustrated in Figure 4. This process begins with the mission statement that is derived from Australia's Strategic Policy [3] and translated into a set of military strategies and Military Response Options (MROs) which form the basis of new preparedness directives [7]. The operational requirements for the RAN are then specified in the Chief of Navy Preparedness Directive [13].

The management process requires assessment processes to answer the questions *"How well* ***has*** *the current capability satisfied the current operational requirement and how well* ***will*** *the current capability satisfy future operational requirements?"*. The formal process for verifying this is through the Capability Assessment Reporting (CAR) process and the Capability Management Boards (CMB) [14]. The CAR and the CMB processes highlight deficiencies in capability however, quantitative approaches have yet to be put in place to support this management process.

In the capability management process, both the MOEs derived from the operational requirements and the MOPs of the current capability are used to assess whether the current capability can adequately meet the operational requirements. This assessment process requires MOEs and MOPs to be:

- timely (that is, they can be evaluated within a specified time period),

[1] DI(AF) ADMIN9/98 addresses capability management of systems "... from development through to maturity, and replacement where appropriate...".

- relevant (that is, related to requirements which may change with time),
- inserted at the appropriate points in the management hierarchy,
- meaningful to the management level,
- recorded,
- tested (to ensure that data are not biased).

If the outcome of the assessment process is that the operational requirements are not met, or in the future will not be adequately met by the current capability then appropriate action needs to be taken. For example:

1. the capability may need to be changed during its life-cycle,
2. a new capability may need to be introduced,
3. the training may need to be enhanced,
4. the Integrated Logistics Support (ILS) may need to be modified, or
5. the operational requirements may need to be redefined.

Decisions to change the capability or introduce a new capability involve risk-management decisions, such as, cost/capability trade-offs and re-evaluation of operational requirements. The greatest difficulty in the capability management process is assessing **how the capability will meet operational requirements in the future**. The capability management process is a dynamic process involving risk management and continuous improvement as illustrated by the feedback loops in Figure 4.

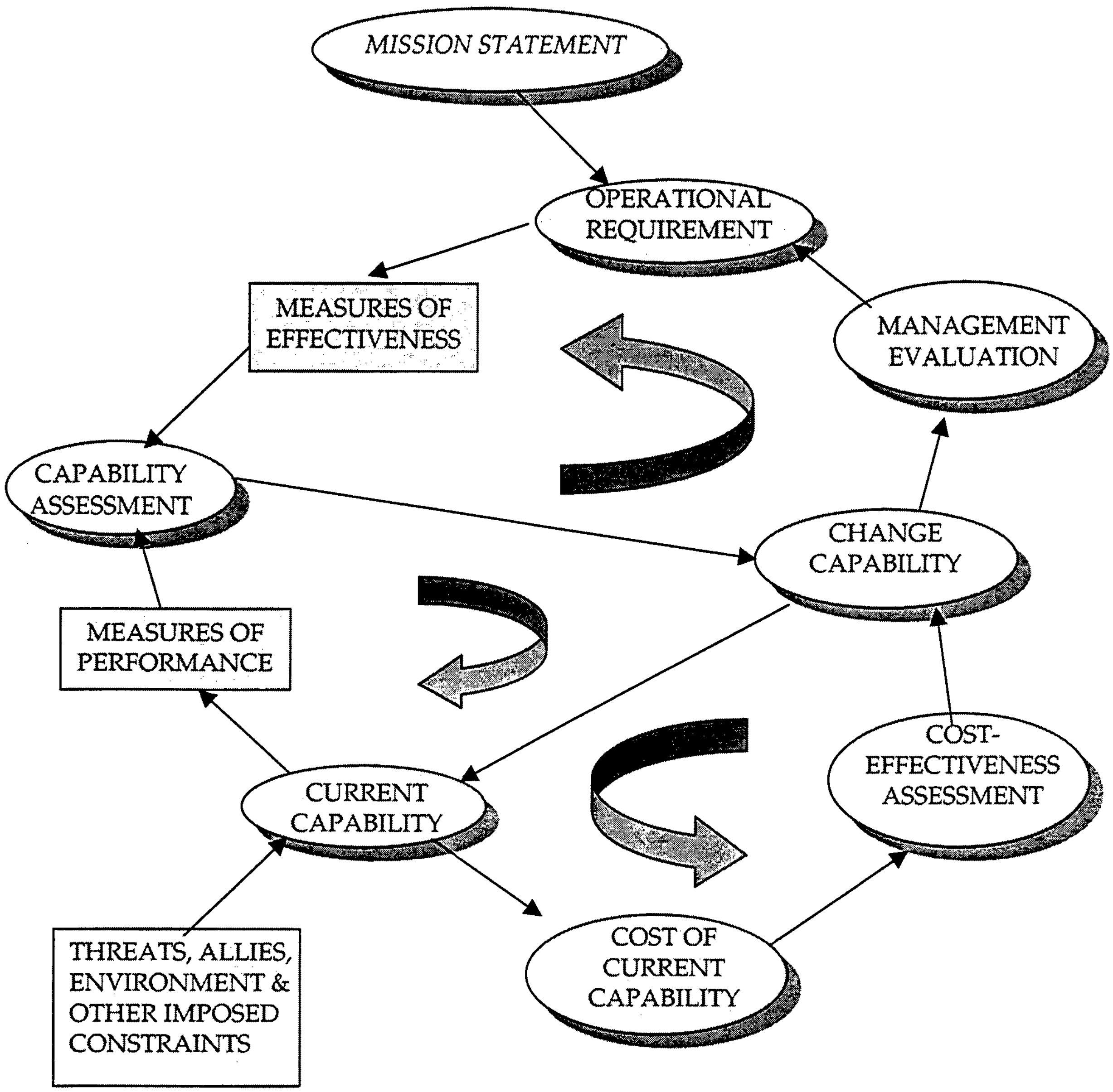

Figure 4: The capability management process.

3. Quantitative Processes In Capability Management

The systems approach to capability management has the potential to provide quantitative measures that can be applied to all levels of the RAN capability management process. Specific issues that need to be addressed for quantitative capability management are:

1. insertion of measurement points in the organisational structure for capability management;
2. integration of capability development and capability management;
3. ability to measure performance in response to a changing environment;
4. risk management and decision making processes; and,
5. continuous improvement in the capability management process.

These issues are briefly addressed in the following sections.

3.1 Insertion of Measurement Points in the Organisational Structure for Capability Management

A description of how measurement processes may be embedded within the current RAN organisational structure is given in this section. The measurement points and areas of influence in capability management for the Maritime Commander, Commodore Logistics Support (Navy) and the Class Logistics Managers are shown in Figure 5.

The purpose of Figure 5 is to show that capability management will often require different information to be available to the various management levels in the process. For example, the Maritime Commander is primarily concerned with the performance of the fleet and facilities whereas the performance of an individual component or system on board a RAN platform is the concern of the relevant Class Logistic Manager. In this example, a RAN platform (which is a collection of interacting systems) can be managed individually, yet this platform contributes to higher-level requirements in conjunction with similar and/or different platforms. Therefore, it is important to determine the relevant information for each managerial level and to put in place the appropriate MOPs and MOEs.

Informed decision making is dependent on establishing measurement points within the capability management process that are consistent with articulated operational requirements for the capability. The measurement points in Figure 5 that are used to show the appropriate MOPs and MOEs need to be inserted at various positions within the business processes. The purpose of these measurement points is to set targets or benchmarks to be achieved that enable the responsible managers to understand how well the process is performing [2].

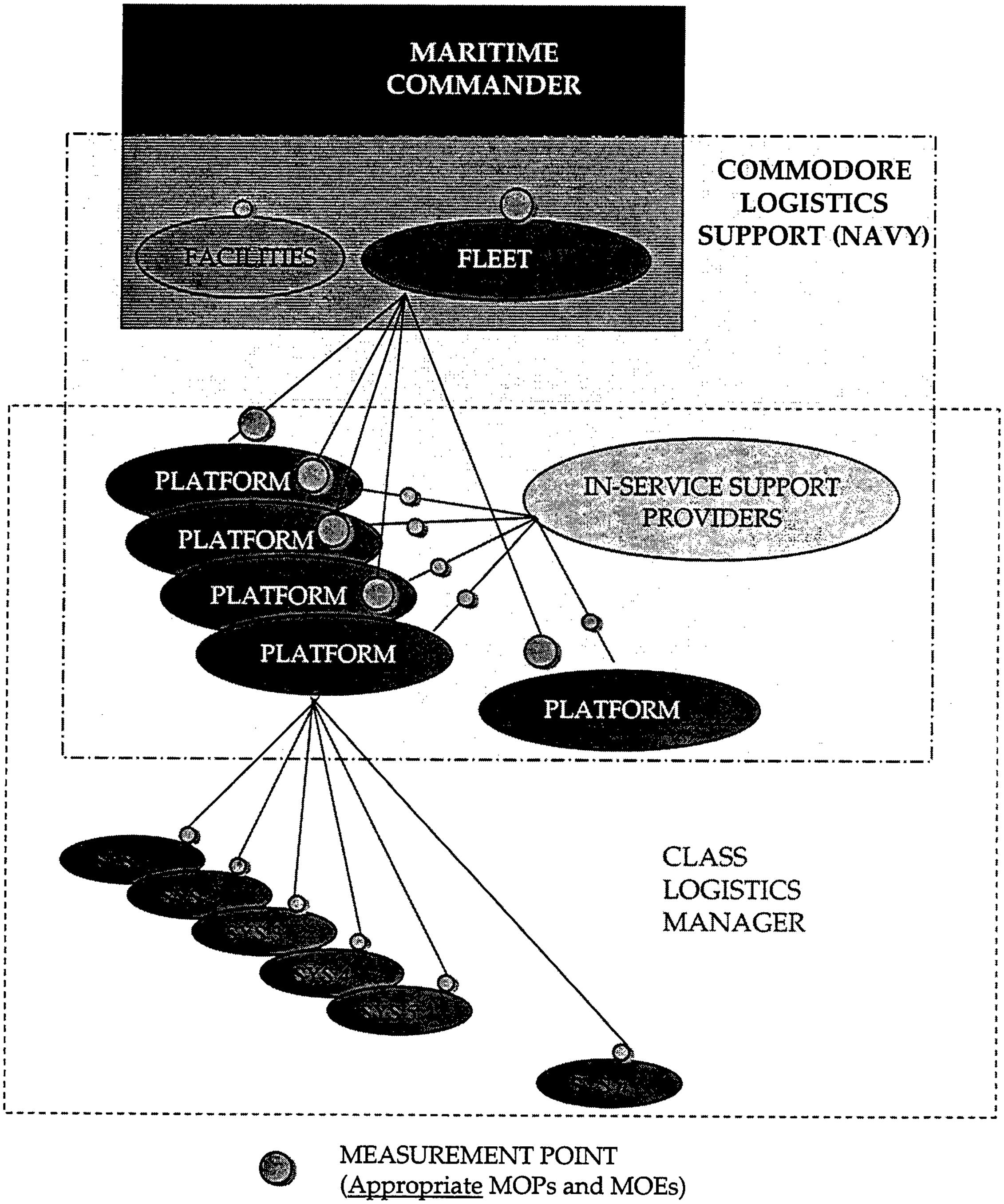

Figure 5: The Hierarchy of Capability Management

Deciding *where* to place these measurement points is a critical issue in the design of the capability management process. At all levels, the measurement points must be capable of capturing information relevant to the operational requirement of the capability. The three principal classes of performance information (which will be measured against performance benchmarks) are:

1. technical,
2. financial, and
3. human (for example, training and in-service support competencies).

Measured characteristics at many of the measurement points will be related. For example, financial performance may have a strong impact on training and hence human performance.

In many management systems it is often possible to find that the performance measures used are those that are easy to measure. However, they may not convey information as to how the system is functioning. For example, from a Defence perspective, there are few performance measures that are related to mission reliability, sustainability and cost effectiveness [2]. This reference also notes that:

> *"... there are no agreed benchmarks for performance measures in an operational planning sense. The type of information available is historic, giving no indications of future trends or outcomes...".*

The result is that operational requirements are usually adjusted to accommodate platform availability rather than operation requirements driving the availability[2].

3.2 Integration of Capability Development and Capability Management

It is important that the capability management process is not separated from the capability development process. It could be argued that the capability management process commences before assets are acquired. As with all logistics processes, down-stream processes are affected significantly by decisions made in the early stages of capability development. There is an obvious requirement that all of the supportability (and configuration) information will be transferred to the operational and support phases of the asset's life-cycle and that it will continuously be maintained throughout the life-cycle of the asset. Assets are often managed in an information-poor environment because management processes are not in place to maintain such information throughout their lives. Additionally, the performance characteristics of assets are often evaluated under "test-bed" conditions and therefore do not reflect their performance within the larger Defence environment. Therefore, management processes, including sparing, maintenance scheduling and maintenance are often based on inappropriate data which are irregularly updated (if at all). Further, new roles and tasks that are outside the asset's original design may evolve for an asset after its operational life begins. Processes need to be developed to clearly state the desired capability of assets and their support requirements continuously throughout the life-cycle.

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[2] Another issue is whether "availability" (various definitions) is an appropriate performance measure.

This has been partially addressed in two areas relevant to RAN assets:

1. RAN's Detailed Operational Requirements document (DOR) for assets is to become a "living document" which will capture changing capability baselines in response to changed operational requirements [13]. This document will become the Capability System Statement;
2. Integrated Logistics Support (ILS) arrangements will be maintained throughout the life of the asset [15] that includes formal processes for the through-life maintenance of the ILS documentation for ADF assets. Collection and management of asset and in-service support provision performance data will be essential to the maintenance of through-life ILS data.

3.3 Ability to Measure Performance in Response to a Changing Environment

One of the greatest problems inherent in the RAN capability management process is that the process is largely undertaken under peacetime conditions and information derived from these conditions does not readily extrapolate to contingency conditions. Information and management processes from peacetime operations may become less relevant and/or inaccurate when in an environment of increasing threat levels. Therefore, the capability management process must include strategies and contingencies to ensure preparedness of assets under all credible operational conditions.

Preparedness is defined in terms of readiness and sustainability [14]. Readiness implies that ADF assets must be at a particular level of operational capability. This includes equipment and its condition, personnel and their level of training. Readiness of RAN assets is currently assessed internally and stated as Minimum Level of Capability (MLOC), Operational Level of Capability (OLOC) and Present Level of Capability (PLOC). These "measures of capability" need to be assessed quantitatively. Collected data may be representative of past and current capability in response to a range of operational conditions but this is only a subset of all possible operational conditions. Unfortunately, difficulties still exist in determining the MLOC to OLOC dynamic [8] because principally there is still no way of quantifying the relationship of platform systems to operational requirements. The development of suitable MOPs and MOEs will provide a mechanism to quantify the relationships between platform systems and operational requirements and this is the focus of current research [10].

Sustainability is the capacity to support ADF forces in operations and includes the adequacy of material support, relief of personnel and serviceability of assets whilst ADF forces are deployed. This includes the ability of industry to maintain a surge capacity for the continual supply of materiel and equipment. It is particularly difficult to assess sustainability because it is an attribute of the capability management process that is forward-looking and must consider more than one operational scenario. **Sustainability modelling presents significant challenges** and further work in this area is highly desirable if preparedness decisions are to be made based on a high level of quantitative information.

3.4 Risk Management and Decision Making Processes

It is also instructive to view capability management as a risk management process, that is, the risk of an action or the risk of inaction to address an identified shortfall in capability. This is embodied in the CN proposal [13] for Navy Capability Management that states:

"... an essential feature [of capability management] is managing the risk associated with maintaining a credible capability for the prevailing and emerging strategic situation and environment of high technological change and limited resources ...".

From a risk management perspective, the management processes must be forward-looking. Decision making in risk management will need to be undertaken using quantitative data. These data will be used to calculate the two components of risk: the likelihood of an event happening; and the consequences of that event. For example, the risks of using a particular maintenance or sparing policy could be identified before the policy is implemented. Decisions in risk management will often involve cost/capability trade-offs and formal processes such as selection of evaluation criteria, weighting of evaluation criteria and the use of ratios as means of evaluation scoring [16]. Decisions may also be made on the basis of data generated by modelling and simulation and using decision-making tools.

3.5 Continuous Improvement in the Capability Management Process

The use of quantitative measures means that the performance of RAN assets can be tracked in time. These data can be used to continuously improve the assets and the management process. Most importantly, the quantitative measures (MOPs and MOEs) used in the capability management processes need to be continuously tested to determine their appropriateness to the current or "new" operational conditions. It is not sufficient to put MOPs and MOEs in place and assume they will never require modification. As new assets are introduced into the ADF, new methods of testing or training may be required. Also, the measurement points in the capability management process may either, not be appropriate, or not be located in the same place in the management process.

The level and quality of services such as training, refit capability, maintenance and facilities that are supplied by in-service providers will also change over time. The capability management process must be sufficiently responsive such that it both captures the changing in-service support services and that the process itself is responsive to any changes.

4. Application Of Modelling And Simulation To The Capability Management Process

What has been discussed so far in this report is the dynamic nature of capability management. Capability management is principally concerned with how RAN assets are going to behave in the future. The main purpose of modelling and simulation is to predict the behaviour of systems when constrained to a particular set of operational conditions. The results of modelling and simulation for the capability management process are appropriate MOPs and MOEs for all possible requirements. This will lead to informed decisions in risk management, including assessment of different management strategies and the ability to determine areas of deficient performance.

There are three main constituents required for the successful application of modelling and simulation to the capability management process. These constituents are:

1. models must accurately reflect reality[3] (this includes both the equipment and their operators);
2. appropriate data must be gathered for input to the models; and,
3. predictions are thoroughly assessed for their accuracy and relevance.

The models will be described by entities (objects), the attributes or properties of the entities, the functions performed by the entities, the inputs, outputs and states and the rules governing the interaction of the entities, including the business rules. For example, in the case of the Maritime Defence Assurance System (MDAS) project [5, 6] a set of business rules has been developed to govern the interaction of entities.

When applied to capability management, modelling and simulation has the potential to provide mechanisms which allow the exploration of the outcomes of plausible (and not so plausible) scenarios, requirements, inputs and constraints applied to specified systems. The virtual history so generated provides guidance to managers ***before*** scenarios are encountered. Therefore, through the application of modelling and simulation, the capability manager has the opportunity to develop strategies and contingencies before a plausible scenario becomes reality. Modelling and simulation will allow management decisions to be made on the basis of ***many*** scenarios. Historical data can be used to validate that the modelling and simulation process has indeed predicted the outcome of the actual set of operational conditions. This is one validation technique (others are listed in Section 5.5) and can only be used if the historical data is available. Mean time to failure, mean time to repair, power output and charging rate are all examples of physical performance data captured by management information systems such as Anzac Ship Maintenance Planning System (AMPS), Submarine Information Management System (SIMS) and Submarine Information System (SIS). The data from these platform information systems may be used in the modelling and

[3] The results and conclusions of the modelling and simulation are not significantly affected by the simplifications and assumptions made in the models.

simulation process. However, this provides little guidance about how assets may behave under conditions significantly different to the conditions for which they were acquired. The role of modelling and simulation as the forward-looking capability management process is summarised in Figure 6.

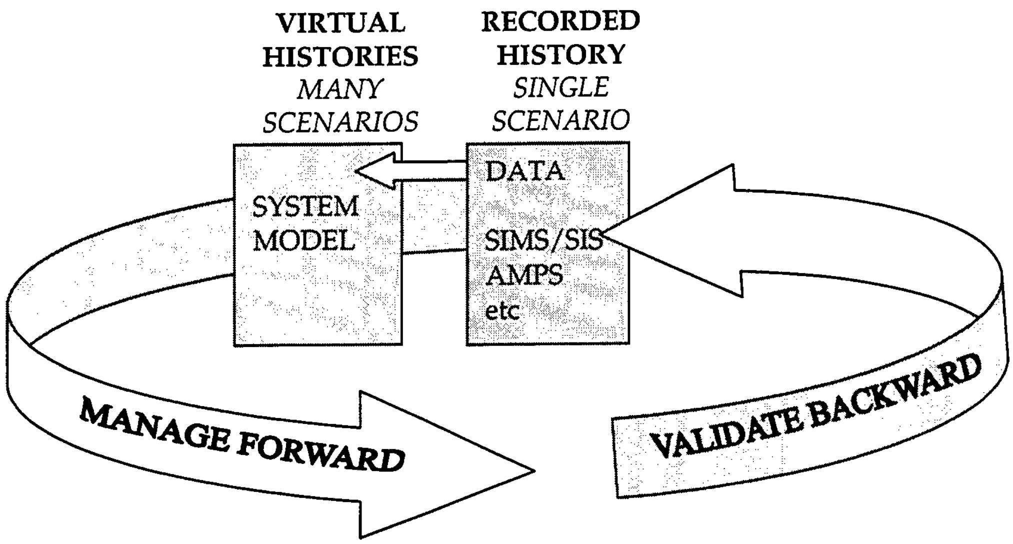

Figure 6: Modelling and simulation as the forward-looking capability management process.

The manager who uses modelling and simulation can better assess the consequences of decisions compared to the "intuitive" manager who relies on personal experience and the experience of others. The manager who uses modelling and simulation is able to **augment** "intuitive" processes by exploring a wider range of scenarios where no experience has been gained. For example, an acceleration of system usage may result in the "intuitive" manager increasing the sparing rate, but modelling and simulation may show that, for this scenario, sparing rate need not increase[4].

Modelling and simulation provide methods that allow "discovery" of problems and sensitivities to internal RAN processes and external environmental constraints, and allow the concurrent investigation of *many* scenarios in the capability management process. This is highly important when there is human activity in the system, since no performance of human activity is exactly the same[5].

Some of the areas of **capability management** in which modelling and simulation can be used are: critical systems analysis, risk analysis, reliability, availability and maintainability analysis, obsolescence analysis; and resource allocation analysis.

[4] Hypothetically, under increased usage equipment is not turned off-and-on, thus thermal fatigue is decreased resulting in a decreased sparing rate.
[5] The use of "standard operating procedures" etc attempts to overcome this difficulty and often failures in human activity systems can be attributed to "non-standard" procedures.

Critical systems analysis involves identifying system failures that could result in non-completion or incomplete performance of an operation and additional **risk analysis** identifies failures that could result in loss of life, injury or illness and significant loss of, or damage to, the asset. One of the purposes of **reliability**[6], **availability**[7] **and maintainability**[8] **analysis** is to predict the performance of assets. This analysis, when combined with modelling and simulation allows exploration of a range of different scenarios, such as the impact of different maintenance schedules and levels of crew experience. **Obsolescence analysis** is used to identify components and systems that present a significant risk to a system because of discontinuance of production, change of specification or change of manufacturer. **Resource allocation analysis** may include optimisation of sparing levels, crew training and different maintenance schedules for changes in usage, operational roles and operating environments.

5. Numerical Techniques For Capability Management

In this section some of the numerical techniques that could be applied to the capability management process are briefly discussed. These include: modelling and simulation techniques; multi-criteria decision-making techniques; artificial neural networks and expert systems; and, knowledge discovery techniques. This is followed by a brief description of verification and validation techniques. The use of these numerical techniques will assist the capability manager in the decision-making process.

5.1 Modelling and Simulation Techniques

There are basically three mathematical techniques for predicting the response of an asset when constrained to a particular scenario or set of conditions:

1. trend analysis using historical data,
2. analytic models and,
3. simulation models.

The main assumption of **trend analysis** using historical data is that the asset being analysed will respond in the same way as in the past. Therefore, if a future event has not also occurred some time in the past then trend analysis cannot predict how the asset will respond to this event. For example, the effects of aging and the consequences

[6] Reliability [17] is "the inherent characteristic of an item related to its ability to maintain functionability when used as specified". This is a function of the item's inherent factors (eg. strength), environmental factors (eg. influence of temperature) and operational factors (eg. technical education of users).

[7] The term availability [18] is used differently in different situations. The availability defined here is the operational availability and is "the probability that a component or system, when used under stated conditions in an *actual* operational environment, will operate satisfactorily when called upon".

[8] Maintainability [17] is "the inherent characteristic of an item related to its ability to be restored when the specified maintenance task is performed". This is a function of the personnel factors (eg. influence of skill, motivation), conditional factors (eg. influence of operating environment) and environmental factors (eg. temperature, humidity).

of preventative maintenance cannot be predicted using trend analysis on historical data. **Analytical models** use sets of equations to describe the behaviour of the asset and then attempt to solve them. However, the equations involved (even for a small system) are extremely complex and therefore a number of simplifying assumptions must be made in order to obtain a solution. One of the most common simplifications is to assume a constant failure rate, otherwise it is impractical to solve the equations. For example, the consequence of using a constant failure rate is the probability of a system failure will be the same whether the system is one month old or a hundred years old, and whether it has undergone maintenance or not. **Simulation models** use statistical sampling to create events in time and simulate the behaviour of the asset as a function of time in response to these events. Unlike both trend analysis and analytical models, simulation models consider all possible behaviour (or states) of an asset and for this reason alone is the preferred mathematical technique.

5.1.1 Modelling and Simulation Tools

In developing models, and applying simulation techniques to these models, it is important to define what "a model" means. In the context of this report, [19] provides an appropriate definition. A model

> *"... is the explicit interpretation of one's understanding of a situation, or merely of one's ideas about that situation. It can be expressed in mathematics, symbols or words, but it is essentially a description of entities, processes or attributes and the relationships between them ...".*

One important feature of the modelling process is that it often incorporates the modeller's view of the system or situation, thus the modelling process has a high level of human involvement. While different humans may produce different models, the expectation is that the model is still an effective representation of the system or situation[9] under study. This highlights the importance of verification[10] and validation[11] in the modelling process.

5.1.1.1 Reliability Block Diagrams and Fault Trees

Reliability block diagrams [21] are a graphical representation of the serial and parallel functional relationships that exist between components and systems that are required for the overall asset's performance. If each component and/or system can be characterised by a function describing its failure with time then the results from the analysis will be a time dependent function that describes the reliability of the overall

[9] The modeller has the discretion to draw boundaries defining the system or situation, thus influencing the modelling process. The modelling process should therefore be approached from a systems engineering perspective to ensure that the model meets the customer's requirements.

[10] Verification is "determining whether a simulation model performs as intended".[20]

[11] Validation is "determining whether a simulation model is an accurate representation of the real world system under study". [20]

system. It can also show what systems and components are important with respect to failure and provide insight into system behaviour.

Reliability block diagrams [21] can be directly converted into **fault tree diagrams,** which show the logical connections between failure events in relation to the defined 'top-level' system failure. Fault tree analysis can be used to quantify the 'top-level' system failure probability.

5.1.1.2 *Influence Diagrams and Decision Trees*

Influence diagrams and decision trees [22] are two complementary approaches that can be used for structuring decision problems and, depending on the nature of the problem, one approach may be preferred. The decision analysis tools have different advantages for modelling complex decisions. Influence diagrams and decision trees are isomorphic, that is, any properly constructed influence diagram can be converted into a decision tree, and visa versa. An **influence diagram** is a simple graphical representation of a decision problem. The elements of the decision problem, that is, the decisions to be made, uncertain events and the value of outcomes, are all represented by different shapes in the diagrams. These shapes are then linked with arrows in specific ways to show relationships between the elements. Influence diagrams are very good for showing a decision's structure, but they hide many of the details. A **decision tree** can be used to show the details that are hidden or embedded in an influence diagram. A decision tree represents all possible paths that a decision-maker might follow through time, including all possible decisions and outcomes of chance events.

5.2 Multi-Criteria Decision-Making Techniques

There are many multi-criteria decision-making techniques that could be applied to the capability management process. These techniques can be used in two different ways: to capture the decision-maker's preference; or, they can be used in further analysis of modelling and simulation outputs. Two of the more popular techniques, the Analytic Hierarchy Process (AHP) and Multi-Attributed Utility Theory (MAUT), are briefly described in this section.

5.2.1 Analytic Hierarchy Process (AHP)

AHP [23] is a multi-criteria decision-making technique that allows consideration of both objective and subjective factors in selecting the best alternative. AHP is one of the most popular multi-criteria decision-making methodologies available today and has been used in a wide variety of applications including resource allocation, predicting likely outcomes, cost benefit analysis and supplier evaluation. AHP decomposes the decision problem into a hierarchy. The hierarchy consists of the general goals and objectives at the highest level, the next level or levels down contain the more specific attributes and the lowest level consists of the alternatives. Pairwise comparisons are then made between the elements of each level in relation to their parent level. This produces the local priorities of each element in the hierarchy. The local priorities in the various levels of the hierarchy are then used to construct a composite (global) set of priorities for the alternatives (that is, the elements at the lowest level of the hierarchy). AHP has also been extended for decision problems that cannot be decomposed into a hierarchy or where only a partial hierarchy exists. In these problems there may be dependencies and feedback and therefore it is more appropriate to use a network in replace of a hierarchy. This process is called the Analytic Network Process (ANP) and has not been applied as extensively as AHP since it is a relatively new concept [23].

5.2.2 Multi-Attributed Utility Theory (MAUT)

MAUT is a technique that uses the decision-maker's preferences, involving uncertainty, risk and other factors, in selecting alternatives. In MAUT, the decision-maker's preferences are captured in the form of a non-linear utility function for each individual attribute or quantitative performance measure. These single attribute utility functions are then combined into a multi-attribute function, which is a single index of the overall desirability of an alternative. Probability distributions are used to quantify uncertainty in the multi-attribute function. MAUT provides a method of combining MOPs and other quantifiable factors into MOEs.

5.3 Artificial Neural Networks and Expert Systems

Artificial Neural Networks (ANNs) and expert systems are often thought to be competing forms of artificial intelligence. However, it is more appropriate to consider them to be quite different approaches, each with distinct strengths and weaknesses. **Expert systems** depend on rules (IF-THEN) and are good at sequential logic. **Artificial Neural Networks,** on the other hand, depend on examples, and are good at pattern recognition. ANNs are trained on sets of data that have known outputs and are then used to predict the output of a set of data that was not used during training. For example, the capability manager may be concerned with some of the parameters that might influence the reliability and operational life of an engine, such as, oil pressure, average temperature, minimum and maximum temperatures, acceleration, deceleration and average speed. Given sufficient data sets on which to "train" an ANN, it may be possible to create a reliable *predictor of critical values* of these parameters.

5.4 Knowledge Discovery

Although **knowledge discovery** [24] is not a modelling and simulation technique, it has the potential to complement modelling and simulation. Knowledge discovery may also provide information that will be used in the validation and verification process for models and may additionally provide guidance on where potential problems lie in the systems under study.

Knowledge discovery is an automated technique used for the "discovery" of patterns or relationships, within data sets, that may not be readily seen by standard observation and analysis. Knowledge discovery does not require a priori knowledge or the development of hypotheses concerning the structure of data relationships. The method uses various algorithms to cluster the data or determine relationships and patterns. This information may then be used for optimising various aspects of an asset or alternatively to advise modelling strategies.

Knowledge discovery is most effective when applied to large data sets, such as data stored within a data warehouse. Thus, with more data, it is possible to form stronger relationships. In this area, the RAN has in operation "on-line" data collection and management systems associated with its assets (such as, AMPS and SIMS/SIS) and additional information relating to maintenance of the assets, training, crew competencies, etc are maintained within these data systems. Provided this data is collected accurately and is well maintained it should be possible to perform analysis on data sets using knowledge discovery techniques.

5.5 Verification and Validation

The final phase that a model, using any of the above numerical techniques, must undergo before being accepted for general use is that of verification and validation. An explanation of both these terms is given below.

5.5.1 Verification

Verification is determining whether a model performs as intended [20]. The following techniques may be used for verification:

- thoroughly debug all subroutines, systematically connect subroutines into the main code and at all stages test the outputs of the main model;
- trace the flow of logic through each sub-module and the main model, and test each state that the model can enter;
- start with a simple model and gradually make it as complex as required rather than starting with a complex model;
- perform "structured walk throughs" of the code and have several people read and evaluate the correctness of each sub-module and the main model;
- test the model's ability to deal with "extreme" conditions;
- test the model using simplified assumptions for which the true characteristics of the model are known; and,
- use graphical outputs if possible to see the progression of simulation models.

5.5.2 Validation

Validation is determining whether a model is an accurate representation of the real world system under study [20]. The following techniques may be used for validation:

- the model should seem reasonable to those people with knowledge about the system being modelled;
- the system being modelled needs to be observed and analysed so that the variables that are used are representative of what is actually modelled;
- test quantitatively the assumptions used in development of the model, such as, using "sensitivity analysis";
- test the model's outputs with what might be reasonably expected from the actual system under study;
- if possible, test the results against other similar models;
- test against historical data; and,
- use statistical tests to compare the model's output with that of the system under study.

6. Summary

This report has provided an overview of the role of modelling and simulation in RAN capability management. Capability management is a forward-looking dynamic process and as this report has shown, needs to be based on suitable quantitative measures. These measures include appropriate MOEs and MOPs that inform the capability manager on whether a particular system or collection of systems will be **able** to satisfy current and future operational requirements. This assessment process along with other assessment processes, such as, cost/capability trade-offs, is part of the capability management process.

A number of specific issues for quantitative capability management have been addressed in this report. These included: the insertion of measurement points in the organisational structure for capability management; the integration of capability development and capability management; the ability to measure performance in response to a changing environment; risk management and decision making processes; and, continuous improvement in the capability management process.

Capability management is principally concerned with how RAN assets are going to behave in the future. The application of modelling and simulation to capability management will provide a means of predicting the future behaviour of RAN assets and systems. This will enable capability managers to make more informed decisions by allowing them to evaluate several possible alternatives before choosing their course of action. Some of the materiel support areas of capability management in which modelling and simulation can be used are critical systems analysis, risk analysis, reliability, availability and maintainability analysis, obsolescence analysis and resource allocation analysis.

Some of the numerical techniques that could be used for capability management were also discussed in this report. These techniques and tools included simulation models, multi-criteria decision-making techniques, artificial neural networks and expert systems, and, knowledge discovery techniques. The simulation models could be based on either reliability block diagrams (fault trees) or decision trees (influence diagrams) and the multi-criteria decision-making techniques could be used to capture the decision-maker's preferences or to further analyse the modelling and simulation outputs. A brief description of verification and validation techniques was also presented.

In conclusion, capability management when based on quantitative measures has the potential to add significant value to the decision-making process of the capability manager.

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8. Acknowledgements

The authors wish to acknowledge COMLOG(N) as the sponsor of this study. The authors would like to acknowledge valuable discussions with Captain Boyd Robinson (RAN), Commander Steve Becsi (RAN) and Lieutenant Commander Brion Snyder (USN). Also, the authors would like to acknowledge Dr R. G. Body of Maritime Operations Division for his constructive comments on this report.

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David Saunders, Moya Tyndall and Tom Whitehouse

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2. TITLE The Role of System Modelling and Simulation in Royal Australian Navy Capability Management			3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)			
4. AUTHOR(S) David Saunders, Moya Tyndall and Tom Whitehouse			5. CORPORATE AUTHOR Aeronautical and Maritime Research Laboratory PO Box 4331 Melbourne Vic 3001 Australia			
6a. DSTO NUMBER DSTO-GD-0244	6b. AR NUMBER AR-011-483		6c. TYPE OF REPORT General Document		7. DOCUMENT DATE July 2000	
8. FILE NUMBER 510/207/1051	9. TASK NUMBER NAV98/061	10. TASK SPONSOR COMLOG(N)		11. NO. OF PAGES 24		12. NO. OF REFERENCES 24
13. URL http://www.dsto.defence.gov.au/corporate/reports/DSTO-GD-0244.pdf				14. RELEASE AUTHORITY Chief, Maritime Platforms Division		
15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT *Approved for public release* OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, SALISBURY, SA 5108						
16. DELIBERATE ANNOUNCEMENT No Limitations						
17. CASUAL ANNOUNCEMENT Yes						
18. DEFTEST DESCRIPTORS Royal Australian Navy, Defence planning, Modelling, Management systems, Measures of Effectiveness, Simulation						

19. ABSTRACT

This report examines the Navy Capability Management process that has evolved from the 1995 review of RAN logistics support and in response to the more-recent Government focus on output based management of ADF assets.

This report seeks to show that capability management should be based on quantitative measures, including the insertion of Measures of Performance and Measures of Effectiveness at appropriate points in the management process. Capability management must also refer to operational requirements and is therefore a requirements-driven process. However, the principal difficulty with this management process is the lack of processes and supporting tools. Modelling and simulation are presented in this report as a means of addressing this difficulty. The main purpose of modelling and simulation is to predict the behaviour of ADF assets (RAN platforms and platform systems) in response to their environments. Environments in this context refer to changing operational requirements and constraints both within and external to the model.

Capability management is a forward-looking, dynamic process and therefore there is a need to develop matching dynamic models as capability management tools. There is no single model that can be generally applied to the many capability management problems however; modelling may be applied effectively to address specific management and technical issues. Models representing the RAN platforms and platform systems, when applied in a simulation process under a range of conditions, can provide useful capability management information. This information may be used to develop appropriate quantitative performance measures.