A cost optimisation of preventative upkeep networks using the South African Navy as a case study

by

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March 2014

Declaration

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Signature: ....

Date: ....

Abstract

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March 2014

The South African Navy (SAN) intends to reinstate Naval Station Durban (NSD) as a fully operational support base for a new class of Offshore Patrol Vessels (OPV's) which the SAN intends to purchase. These acquisitions must be seen against the background of strategic and political considerations in general, and in particular threats to South Africa's maritime security, due to the possibility of the piracy, along particularly the West African coast, reaching our territorial waters. The aim of this thesis is the development of a cost-optimization model, intended to provide optimal locations for the SAN's support facilities, given the SAN's operational obligations, present and future. In the first part, a literary review of facility location formulation and strategic management principles is an attempt to lay the foundations for the proposed model. The review of this literature is primarily based on extracts of the comprehensive research of other authors. Consequently, the research problem was contextualized and classified as a hierarchical location-allocation problem. The second part of the thesis aims to describe the SAN's environment from a maritime security perspective. Within this framework, formulation was identified and modified to develop a theoretical mechanism to solve the research question. The final part will see the application of the developed model to a case study specific to the situation of the SAN. Validation of the inputs and the model itself proceeded in conjunction with the application of the model. The results and the model itself were validated through visual inspection and independent mathematical validation. This thesis comes to the conclusion that the SAN cannot cost-effectively meet its future obligations by splitting its maintenance capability between Naval Base Durban (NBD) and Naval Base Simon's Town (NBS). Future research may build upon the results of this thesis in order to facilitate a more comprehensive optimization of preventative networks.

Uittreksel

’n Koste optimering van voorkomende onderhouds netwerke deur gebruik te maak van die Suid-Afrikaanse Vloot as gevalle studie

(“A cost optimisation of preventative upkeep networks using the South African Navy as a case study”)

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Maart 2014

Die Suid-Afrikaanse Vloot (SAV) beoog om die vlootstasie in Durban weer op te gradeer na ’n volwaardige vlootbasis vir die beoogde aanskaffing van ’n nuwe klas van patroleringsvaartuie. Die motivering vir die opgradering van Durban kom uit dieper strategiese en politieke behoeftes maar word tans toegeskryf aan plaaslike bedreigings van seerowery en die gevolglike verkryging van nuwe patrollievaartuie om hierdie bedreiging, onder meer, te bekamp. Die doel van hierdie meesters tesis, is om ’n koste optimerings model te vind, of te ontwikkel, wat optimale liggings vir ondersteunings fasilitieite sal lewer, gegewe die toekomstige of huidige verpligtinge van die SAV. Die eerste gedeelte van hierdie tesis bevat ’n literatuuroorsig van fasiliteitsligging-formulering en strategiese bestuursbeginsels. Hierdie literatuuroorsig beoog om die grondslag vir die voorgestelde model te lê. Die oorsig van sodanige literatuur is hoofsaaklik gebaseer op uittreksels uit veelomvattende opsommings deur ander outeurs. Gevolglik is die navorsingsprobleem gekontekstualiseer en geklassifiseer as ’n hiërargiese ligging-toekenningsprobleem. Die tweede deel van die tesis beoog om die omgewing van die SAV vanuit ’n maritieme sekuriteitsperspektief te beskryf. Binne hierdie raamwerk is formulering geïdentifiseer en só gemodifiseer om ’n teoretiese meganisme te ontwikkel om die navorsingsvraag op te los. Die finale deel pas die ontwikkelde model op die spesifieke situasie van die SAV toe. Validasie van die insette sowel as die model self is gedoen in samewerking met die toepassing van die model. Die resultate tesame met die model self is deeglik bekragtig deur visuele inspeksie en onafhanklike wiskundige validasie. Hierdie tesis het tot die gevolgtrekking gekom dat die SAV nie koste-effektief aan sy toekomstige operasionele verpligtinge sal kan voldoen met die verdeling van sy onderhoudsvermoë tussen 'n vlootbasis in Durban en Simonstad nie. Toekomstige navorsing kan op die resultate van hierdie tesis bou ten einde 'n meer omvattende optimalisering van voorkomende instandhoudingsnetwerke te fasiliteer.

Acknowledgements

I would like to express my sincere gratitude to the following people and organisations:

- Prof PJ Vlok, for his accommodating, optimistic and honest approach, always being accessible for guidance.
- Rear Admiral (Junior Grade) Kevin Watson, for providing the opportunity for this study and his dedicated support to the research.
- Capt.(SAN) Chris Dooner, for patiently entertaining my thoughts and questions regarding Naval Base Durban (NBD).
- Tanya Visser, for giving me the freedom to pursue other interests.
- My family for the financial and emotional support during my carefree student life.
- The Dreyer family, whose door was always open.
- The staff of SA Naval College, for making every day away from home worth it.

Dedications

To God, my parents and all my teachers.

Contents

List of Figures

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Nomenclature

Binaries

X	[0,1]
Y	[0,1]

Variables

a	Demand	
β	Weight or probability	
c	Transit cost	
m	Number of facilities to be located	
n	Total number of locations	
s	Total types of facilities (or services)	
W	Total population	
Z	Optimal objective value	
d	Distance	[nm]
F	Fixed cost of building or expanding facility	[R]
V	Unit cost of operating facility	[R]
z	Transit speed	[knots]

Subscripts

h	Index of level of service
i	Index of demand nodes
j	Index of potential facility sites
k	Index of scenarios

List of Abbreviations

AHP Analytical Hierarchy Process

ARMSCOR Armaments Corporation of South Africa

AMP Assisted Maintenance Period

CSR Cape Sea Route

DBN Durban

DM Decision Makers

DED Docking and Essential Defects

DPW Department of Public Works

EC Engineering Change

ECOWAS Economic Community Of West African States

EEZ Economic Exclusive Zone

ELT Eastern Littoral Theatre

FMU Fleet Maintenance Unit

FOB Forward Operating Base

GDP Gross Domestic Product

HAPRO Hull Availability Program

HATS Harbour Acceptance Trails

IPV Inshore Patrol Vessel

MADM multi-attribute decision making

MAUT multi-attribute utility theory

MCDA Multiple Criteria Decision Analysis

MCDM multi-criteria decision making

MEND Movement for the Emancipation of the Niger Delta

MODM multi-objective decision making

MUP Major Upkeep Plan

NATO North Atlantic Treaty Organization

NSR Northern Sea Route

NBS Naval Base Simon's Town

NBD Naval Base Durban

NSD Naval Station Durban

OPV Offshore Patrol Vessel

OR Operations Research

PMC Private Military Company

PSC Private Security Company

ROI Return on Investment

SADC Southern African Development Community

SAN South African Navy

SANAD South African Naval Armaments Depot

SANDF South African National Defence Force

SATS Sea Acceptance Trails

SCTC Strike Craft Training Centre

SIPRI Stockholm International Peace Research Institute

SLOC Sea Lane of Communication

SMP Self Maintenance Period

SMST Simon's Town

WLT Western Littoral Theatre

QAP Quadratic Assignment Problem

UFLP Uncapacitated Facility Location Problem

ULCC Ultra Large Crude Carriers

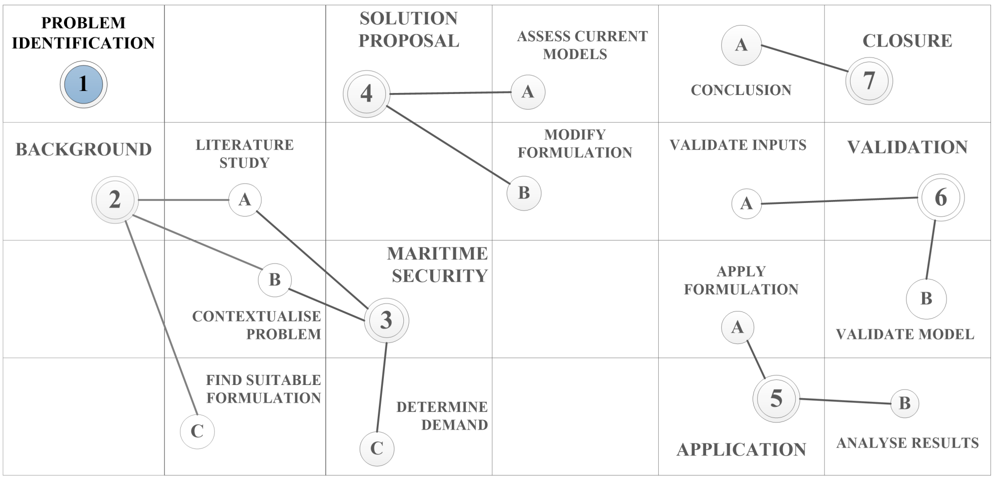
VLCC Very Large Crude Carriers

Chapter 1

Introduction

Chapter Aim:

The aim of this chapter is to introduce the present challenges faced by the South African Navy (SAN) in optimising their upkeep network for a new class of patrol vessel, consisting of support facilities providing different levels of maintenance. From this context a clear problem statement and research objectives are to be derived. Thereafter, the research design and methodology will be addressed according to the central research question.



Chapter Outcomes:

- Demarcation of the research problem.
- Presentation of research objectives.
- Clear scope of the study.
- Adequate research design and methodology.
- Development of the thesis blueprint.

1.1 Background

The South African Navy (SAN) intends to reinstate Naval Station Durban (NSD) as a fully operational support and training base for the planned acquisition of a new class of Offshore Patrol Vessels (OPV's). This is in line with strategic and political policy in general and in particular in view of a threat of South Africa's maritime security, due to the possibility of piracy, along particularly the West African Coast, making its way into our territorial waters. The multi-role OPV's are intended to inter alia counter this threat.

In the 2012 South African Defence Review, Roelf Meyer (2012) paints the world as a vastly interconnected system of states that continues to evolve, consequently creating an ideal environment for international markets to be exploited and geopolitical boundaries to transcend. This evolution, at the same time, has compounded the inequalities in the political, economic, social, environmental and military dimensions. In turn these dimensions foster rapidly changing and dynamic threats which pose a challenge to the current structures, policies and equipment of states. Conventional armies have taken a fundamental post-Cold War-era shift towards a more specialised and rapidly deployable force, but still this mobile force often finds itself unequipped to counter these evolving threats. Modern navies have had to adapt to unconventional roles, especially in the littoral zone. The situation the SAN finds itself in is of no exception.

The re-emergence of piracy along Africa's coastline threatens the peace, security, growth and stability of the continent (Meyer, 2012). The current piracy hotspots are off the Coast of Africa, i.e. the Gulf of Aden and the Gulf of Guinea (Schäfer, 1998). As a direct consequence a growing number of shipping companies have opted to re-route their ships via the Cape Sea Route (CSR) instead of using the Suez Canal (Bowden *et al.*, 2010). According to Schäfer (1998), pirates have extended their activities into Seychelles and Tanzanian waters, even reaching the Indian Coast. This is believed to be due to the increased presence of international anti-piracy task-forces in the Gulf of Aden. Such developments, together with requests from foreign governments, have compelled the Southern African Development Community (SADC) to act to such security threats. South Africa, assuming an economic leadership role in Sub Saharan Africa, committed several naval and air assets to combat piracy in the region, i.e. Operation Copper[1] (Meyer, 2012).

To assist future operations in the Eastern Littoral Theatre (ELT), namely the Mozambican Channel, as well as to complement South Africa's maritime

[1]The deployment of the SAN in the Mozambican Channel to combat piracy, please refer to Section A.2 for more information regarding Operation Copper.

narrative, the SAN plan to acquire a compliment of new (OPVs) and Inshore Patrol Vessels (IPVs) under "Project BIRO" (Fish, 2013). If operations in the ELT are to be maintained for the unforeseeable future, a sustainable support strategy must be implemented. Currently the only fully operational Naval Base available to the SAN is located in Simon's Town, near the southernmost tip of Africa. It is in the ideal location to support operations in both the Indian and Atlantic Oceans but not optimal for either (Schäfer, 1998). The SAN have presently committed themselves to reinstating NBD to support anti-piracy operations and have commenced with "Project RE-SADDLE", escalating the capabilities of Naval Station Durban whilst awaiting parliamentary approval for official reinstatement. NBD had been reduced to a Naval Station in 2002 as part of a cost-cutting measure, known as "Project SADDLE".

Various external factors make the reinstatement of NBD problematic, a vast array of political and socio-economic factors play a conflicting part, some driving and some hampering the official reinstatement. To briefly name a few

· *Accommodation*: Official reports mention that the SAN cannot currently provide accommodation for married sailors in Durban as previous quarters have been handed over to the SA Army during "project SADDLE". The SAN can alternatively lease a block of apartments. This is not ideal from an economic perspective and creates further social dilemmas as military rank structure does not promote sharing of accommodation between ratings and officers. Dividing the apartment block into relevant floors could be an ineffective solution (Capt.(SAN) Dooner and Capt.(SAN) Patrick, 2012).

· *Indian grassroots*: The South African Indian people have a long and proud history of serving South Africa as sailors in the SAN. With the scaling down of NBD to a Naval Station, many sailors and their families were forced to move to the Western Province to continue employment. Recruitment in KwaZulu-Natal has also suffered directly. There are thus both political and social reasons to reinstate NBD.

· *Current human resources*: Personnel already stationed at a facility designated for possible escalation of capability and/or capacity have had, in general, very little if any, exposure or training on platforms similar to those proposed in "Project BIRO". Therefore most of them will have to be trained. This includes training in the support infrastructure services as required and prescribed by the Department of Public Works (DPW). Highly specialised training will be required in order to operate and maintain power generation systems, among others . The downgrading of NBD, combined with the inability of a public organisation such as the SAN to retrench or redeploy some of the personnel, has left NSD with idle employees. A special effort will have to be made to overcome any negative attitudes of personnel who have gotten used to being supernumerary. Conversely, personnel who are unable or unwilling to reacclimatise to a full work load should be discharged (Capt.(SAN) Dooner and Capt.(SAN) Patrick, 2012, A-13).

· *KZN Oils*: The state has a standing contract with KZN Oils to supply its petroleum needs. KZN Oils does not trade in marine fuels, neither in Durban nor in Cape Town, hence significant logistical costs are incurred in supplying the SAN with fuel. In the past the SAN would send a support ship from NBS to Cape Town Harbour, fill up with fuel and sail back and replenish the base's fuel reserves (Capt.(SAN) Dooner, 2013*b*). Currently KZN Oils supplies NBS by road via tankers. This illustrates to some extent the environment in which the SAN operates, where logistical factors (among others) are more burdensome than they otherwise could be.

· *Dockyard*: The Dockyard in Simon's Town (SMST) is currently operated by the Armaments Corporation of South Africa (ARMSCOR), the state-owned arms procurement agency. This arrangement originated in 2003 from a need to retain skilled technicians and engineers at private sector rates and to streamline logistics. This entails the acquisition of spares of a military or commercial nature without the tedious tender processes followed by governmental organisations. Simply put, Armscor was to manage the Dockyard on a commercial basis, as an effective private company would. Recently the SAN has motioned for control of the Dockyard after strikes and retrenchments left the Dockyard with a undesired lack of capability to service the country's naval assets. There is thus this factor to consider: does the Navy focus its resources on managing the Dockyard effectively and outsource third-line maintenance of the new vessels in Durban, or follow another configuration of either outsourcing or maintaining in-house capability in both NBS and NBD?

· *Synchrolift®*: NBD could be reinstated to independently have the necessary high level maintenance capability to support the new OPV's but considerable investments will have to be made to accommodate the new, larger OPV's. A simple example of this would be the synchrolift of 60m in lenght at NBD, which was initially designed to accommodate the smaller Strike craft of 58m and Daphné class submarines of similar length. According to Mr. Fish (2013) the new OPV's could be of length between 85m -90m. The syncro-lift has been designed with the potential to increase capacity but it will need to be physically extended where NBS will only need to install extra lifts and extend the cradle of their synchrolift (Capt.(SAN) Dooner, 2013*a*). For more information on how a synchrolift operates, please refer to Section C.3.

All factors considered, the South African National Defence Force (SANDF) and the SAN in particular operates in a financially constrained environment. The Defence Budget Vote for the 2013/14 financial year amounts to R40,243 billion. This is equal to 1,1% of Gross Domestic Product (GDP) and 3,8% of total government expenditure according to the Parliamentary Budget Speech of 2013. There is a strong feeling within the SANDF that the Defence Budget should reflect global trends in military spending for developing countries, which is 2% of GDP. It is believed that other inefficiencies prohibit the SANDF from reaching its required operational levels irrespective of the overall budget. In FY 2010/11 the compensation of employees rose to 55% of the total allocation (Meyer, 2012). This percentage conflicts with the 40% margin[2] pegged in the 1998 defence review, resulting in the additional 15% being drawn from the operational and capital allocation, effectively negating the operational capability of the SANDF. David Maynier, Shadow Minister of Defence and Military Veterans (Democratic Alliance) stated in response to the 2013 Budget Speech by Minister Mapisa-Nqakula

....expenditure on "personnel" has ballooned to 50% of the Defence budget but many of them are surplus to the needs of the Defence Force; we have to find a way to increase the operating budget and allocate resources to the "sharp end" of the Defence Force.

The point being that the SANDF, retains people who no longer fit their post profile or who cannot be economically employed (Meyer, 2012). This indirectly creates a situation where the SANDF cannot offer competitive salaries to retain the people they need because expenditure is capped out by personnel they do not need at this moment. Which identifies one of the main constraints, and hence the problem statement; how to optimally balance the constrained maintenance resources of the SAN between Durban and Simon's Town.

1.2 Problem Statement

Before the scaling down of NBD, the scope of the base's capabilities and capacity [3] equalled that of a small independent navy. It was home to the Strike Craft Flotilla, Dockyard Durban, South African Naval Armaments Depot (SANAD) Durban, Strike Craft Training Centre (SCTC) and Radio Station Umdhloti. The Dockyard had a very powerful technical support capability that provided

[2]The 1998 Defence Review pegged the defence personnel budget at 40% of the total budget with 30% to be spent on operating costs and the remaining 30% to be spent on capital costs (40:30:30 ratio).

[3]Capability vs Capacity. Capability considers what can be, or needs to be, done. Capacity considers how much can be done by a capability. As an example; While NSD has the capability required to fault find on WARRIOR class ELM 2208 search radars, it does not have the capacity to do so simultaneously on all 3 in inventory.

2nd line and some 3rd line support to other elements of the SAN and full 3rd line and some 4th line support to the strike craft (Capt.(SAN) Dooner and Capt.(SAN) Patrick, 2012).

Maintenance Levels (South African Navy (2008)):

a. First Line. First Line is the maintenance organisation immediately responsible for both the preparation for operation and the initial diagnosis of defects of vessels, their systems and equipment. First Line will denote Ship's Staff doing maintenance tasks.

b. Second Line. Second Line is the maintenance organisation established to provide support for vessels and their systems for which facilities do not exist onboard the vessel to carry out maintenance and repairs. Second Line will denote the Fleet Maintenance Unit (FMU).

c. Third Line. Third Line is the maintenance organisation within the Naval Service to provide support for the vessels and their systems, but excluding the organisation within the First or Second Line. Third Line implies workload for which no facilities or expertise exist within the FMU. Third Line will denote Dockyard, Workshops of the Naval Stores Depot and Armament Depot.

d. Fourth Line. Fourth Line is the private organisation providing repair, modification and reconditioning/overhaul of vessels and their associated equipment for which the facilities, expertise or resources are not available within the SAN. Fourth Line will denote Contractors.

"Project SADDLE" resulted in the official downgrade of NBD, the transfer of the last strike craft to Simon's Town and the closure of FMU, SANAD and the SCTC. The naval station generally moved into the space once allocated to the Dockyard. With the exception of the Senior Ratings mess and the station area, the rest of the island was either transferred to the SA Army or neglected pending sale and transfer to Transnet (Capt.(SAN) Dooner and Capt.(SAN) Patrick, 2012). The majority of the capabilities lost during project SADDLE will have to be regained if NBD is to fully support current and future patrol vessels destined for operations in the ELT. Quayside Support, Maintenance and Repair facilities, Logistical and Human Resource Support and Executive Services are functions that will need to grow from their current state.

Relevant to this thesis is the potential restoration of the Maintenance and Repair capabilities to Durban, and the subsequent restoration or relocation of needed facilities and equipment. This process includes but is not limited to, the allocation of required personnel, addition or relocation of equipment and the constraints directly impacting the provision of efficient support to future OPV's. The opportunity costs associated with having these resources available only in NBS, and possibly have private companies maintain the ships in Durban have to be considered. There are two private companies that are capable of maintaining the ships and managing the respective Dockyards. Babcock taking over from ARMSCOR in SMST is considered a potential solution to the improve the current state of affairs (Capt.(SAN) Dooner, 2013*a*). Southern African Shipyards is capable of managing the Dockyard in Durban since they originally constructed and recently refitted the WARRIOR class patrol vessels in preparation for RE-SADDLE.

To expand on the two private companies considered capable of managing the Dockyards of the SAN:

1. **Babcock**: Babcock is successfully maintaining and managing complex naval assets and infrastructure for the Royal Navy, both nuclear-related and non-nuclear. Babcock has reduced the costs of running HM Naval Base Clyde by about £40 million per year over a ten-year time frame. HM Naval Base Clyde is the home port for the ships and submarines it has in its care, a repair facility for visiting vessels and a very large hotel and leisure facility for the crews of those ships while they are alongside. Amongst its support facilities are a Shiplift and Explosives Handling Jetty which are comparable with only two or three others in the world (Babcock, 2009). If Babcock were to manage the dockyard in SMST, the SAN will have an invaluable opportunity to partner with experienced technicians and engineers and find comfort in their global infrastructure.

2. **Southern African Shipyards**: Southern African Shipyards is located in the Port of Durban, on the East Coast of South Africa. The company has a history of building navy vessels for the SAN, including the SAS Drakensberg (a fleet replenishment vessel), six Naval Strike Crafts and Mine Hunters.

The core attribute of armed forces as a tool of the state lies in its ability to function independently to deliver essential services when needed. If the state loses some function, such as medical care to its citizens, the military should be able to step in and have the capability to fill that role. Hence there is a strategic need for armed forces to have independent capabilities with no direct reliance on private sector functions. This raises the question: what are the strategic implications of having private companies managing and maintaining military assets? According to Capt.(SAN) Dooner (2013*a*) the strategic implications of private companies managing the Dockyard is almost irrelevant, considering that other companies already supporting the SAN could cut the legs out from underneath the Navy. The long term decrease in capability of the SAN to run any Dockyard has to be considered.

The overall problem being:

of what level (line) of maintenance should the equipment, workshops and facilities in Durban be capable, to optimally support the new patrol vessels, be it fully independent, in conjunction with or fully reliant on the capabilities of Simon's Town or a private company

The purpose of this thesis is to determine the optimal balance in maintenance capabilities between NBS and NBD, whilst examining the factors that impact, drive and constrain the addition or relocation of maintenance capabilities to NBD. Facility Location theory will be used to determine the optimal relationship between support facilities, be it in SMST, NBD or function as a network (*location and allocation problem*) between the two over an infinite horizon. This points towards the central empirical question:

to what extent must the South African Navy (SAN) balance its maintenance capability between NBD and NBS to optimally support a new class of patrol vessels in complementing its operational obligations

Which leads to the null hypothesis H_0.

Table 1.1: Null hypothesis.

H_0:	The SAN cannot cost-effectively meet its future operational obligations by splitting its maintenance capability between NBD and NBS.

1.3 Objectives

This thesis attempts to achieve a comprehensive answer to the stated research question by solving a series of related objectives. These objectives will aim to split the research question into more directly solvable tasks. In accordance with the research methodology, some of these objectives may be independent and will be addressed in parallel sequence to others.

The first research objective is to gain an understanding of the key concepts regarding the research domain of this thesis: a thorough literature review provides an academic insight into facility location, the principles of strategic management and the concept of maritime security. In doing so, the literature review provides a foundation, based on publications, to contextualise and classify the goals of this thesis. The second objective is to find within the literature, a theoretical mechanism to solve the research question. Chapter 2 introduces the concept of uncertainty regarding facility location as well as a minor study and identification of proposed solution approaches addressing uncertainty. Chapter 2 concludes with a discussion of the ability of the researched literature to address the research question of this thesis, consequently paving the way for the development of a model.

Chapter 3 complements the literature study but pursues the research objectives of contextualising the physical operating domain of the South African Navy (SAN) as well as the inherent strategic and economic environments. In doing so, the *raison d'être*[4] of this thesis will be derived. The secondary objectives, albeit not less important that the first, will attempt to determine possible future demand areas within the maritime strategic framework.

Chapter 4 attempts to draw from Chapter 2 and Chapter 3 the elements necessary to construct a facility location model that will explicitly solve the primary research objective. A logical methodological approach will be followed to incorporate the different elements identified in the literature study into a single model. The objectives of this chapter is to provide a method, supported by existing literature, that will answer the central research question.

Chapter 5 involves the application of the model proposed in Chapter 4 to a case study and pursues two objectives. Firstly it strives to find a desired solution to the problem presented by the case study, through finding the optimal solution. Secondly, through a sensitivity analysis, the chapter strives to discover the boundaries of the inputs to evaluate the rigidity of the results

Chapter 6 has two main objectives of which the first is to validate the inputs applied in Chapter 5 through the issuing of data questionnaires to experts. The second objective is to validate the model itself through visual inspection and mathematical validation.

The final research objective is to draw a conclusion of the results obtained in Chapter 5 and contextualise them within the strategic framework of the SAN. The defined null hypothesis is consequently tested and accepted or rejected. The research objectives for this thesis is summarised and displayed in Table 1.2.

Note that the objectives of Chapter 2 and 3 and also Chapter 5 and 6 are identically numbered as the chapters are considered adjacent to each other.

[4]The claimed "reason for the existence" of something or someone; the sole or ultimate purpose of something or someone.

Table 1.2: Summary of research objectives.

Chapter 2	
1.	Establish the fundamentals of facility location,
2.	Find a theoretical platform to solve research question.
Chapter 3	
1.	Conceptualise the physical environment of the SAN.
2.	Determine possible future demand regions.
Chapter 4	
3.	Attempt to develop facility location model.
Chapter 5	
4.	Apply developed facility location model.
5.	Evaluate Results.
Chapter 6	
4.	Validate inputs.
5.	Validate model.
Chapter 7	
6.	Draw conclusions from analysis.
7	Determine the state of the null hypothesis.

1.4 Boundaries

To effectively reach the objectives of this thesis, the boundaries of the project will have to be considered. The introduction outlined the theoretical positioning of this thesis and the objectives have been stated. The following explicitly scopes the boundaries of this study.

This thesis focusses on the field of facility location and maritime security and its findings are bound in the environment of operations research and security studies. Unintentionally, as research progressed, it became evident that some principles of strategic management will have to be considered if the solution to the research objective is to be fully comprehended. Therefore the research scope of this thesis, initially residing in the overlapping literature between facility location and security studies, includes basic literature in the field of strategic management (Figure 1.1).

To be more specific and in line with the research objectives, this thesis does not pursue the development of a new facility location model. Moreover, this thesis does not intend to explicitly study the incoherent relationships between facility location , strategic management and security studies. It aims to find a

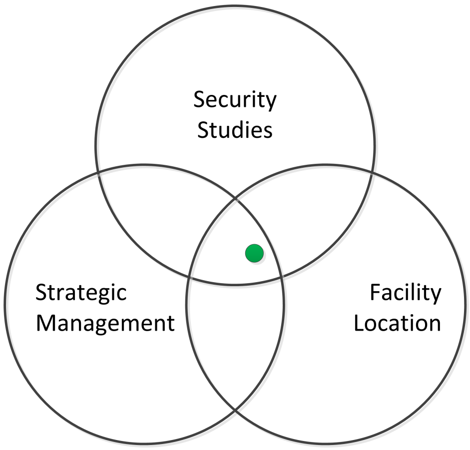


Figure 1.1: Positioning of research focus.

suitable existing model and adapt the constraints or perform modest adjustments, if necessary, in order to obtain more suitable results.

In summary, the following *research* boundaries apply to the thesis:

- The thesis focusses explicitly on optimising a preventative upkeep (maintenance) network, thus only primarily economic and strategic factors are considered. Still, this study acknowledges the interdependencies between social, environmental and political factors and other strategic aspects of facility location, but these do not fall into the direct focus of this thesis and will only find consideration where required.
- The thesis focusses on security studies in the South African maritime domain and does not consider literature on security studies outside the said context unless for comparison or analytical purposes.

Additionally, the following *model* boundaries apply to the thesis:

- The thesis will not aim to develop a new model, but attempt to find existing formulation that can be applied to the research problem, with or without modification.
- The thesis did not have access to the resources nor the time to collect distribution data to estimate uncertain parameters, it will therefore make use of the scenario planning approach, for reasons motivated in the literature study.

1.5 Research Strategy

The research strategy is a process map or blueprint of the intended research process. It encompasses a logical sequence of research methods intersecting with "real-world" assumptions and reasoning approaches. The research methods are the means of data collection, analysis and interpretation. The assumptions are a subjective attempt to find the right balance between "real-world" and ideal model conditions.

A systematic developmental approach was followed as shown in Figure 1.2. First, an approximation of the problem was stated. Thereafter, an initial study was completed, covering literature that was fundamental to the development of the model. This included, but was not limited by, literature on facility location, strategic management and security studies; specifically in the maritime domain. Subsequently, the research problem was contextualised and classified according to literature.

Formulations within the relevant literature were identified as potential solvers and applied to the problem if no modifications are required. The inputs were validated, results were analysed in conjunction with the model validation. The result can then evaluated in along with other strategic factors and be subject to expert validation by stakeholders. Lastly, the research question will be answered and the thesis concluded.

1.6 Thesis Layout

The document layout is aligned to the sequence of the research strategy and the corresponding research objectives, consisting of seven chapters, followed by a list of references and annexures. The chapters are organised to represent the chronological flow of research, except for Chapter 2 and Chapter 3 and also Chapter 5 and Chapter 6, that materialised simultaneously but is presented apart due to the different fields of origin. In addition to the chapter overview below, Table 1.2 provides a summary of the research objectives of each chapter whilst Figure 1.2 prides a blueprint of the research strategy followed.

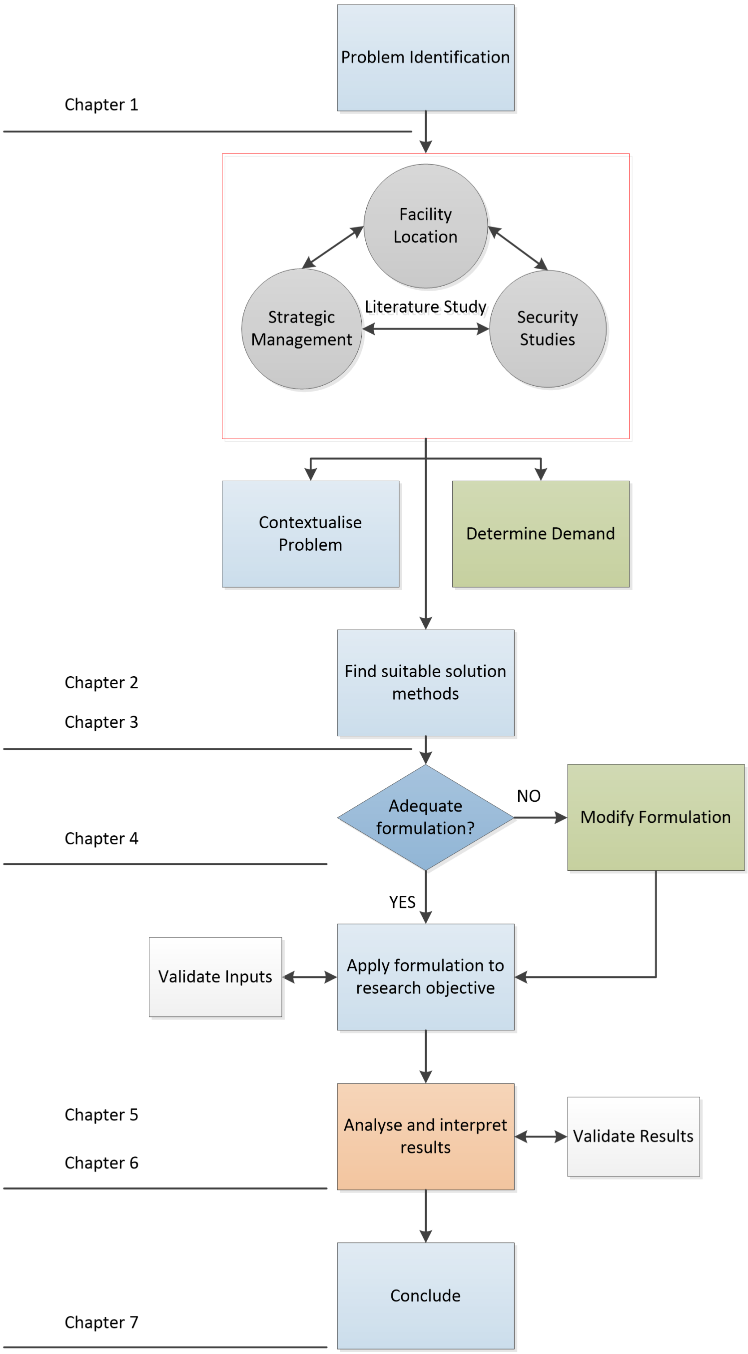


Figure 1.2: Blueprint of research strategy.

Chapter 1: Introduction
The first chapter contains the sections responsible for providing the background to the research problem and well as the motivation for the thesis's existence. The chapter states the research objectives and the delimitation of the thesis. Lastly, the chapter provides a research strategy presented in the form of a blueprint followed by a thesis layout.

Chapter 2: Literature Study
Chapter 2 introduces the concepts of facility location, strategic management, scenario planning and the inherent fundamentals required to develop a solution to the research objective. The chapter starts by investigating existing facility location formulations and then proceeds, as directed by literature, to the study of strategic management in the public sector. The frequent occurrence of uncertainty in location models, combined with the limited ability to procure data for probability distributions, forced the investigation of scenario planning approaches. Lastly, a review of decision making models is presented.

Chapter 3: Environment of the South African Navy
Chapter 3 presents the physical environment of the South African Navy (SAN) within the context of maritime studies. It introduces the physical dimensions of the South African coastline and EEZ to give context to the SAN's international hydrographical and maritime search and rescue obligations. Chapter 3 defines maritime security in the appropriate context and expands on the economic importance of the maritime domain of Africa as a whole. The chapter offers an economic analysis and force comparison between Sub-Saharan Africa and Germany before it represents the economic costs of piracy to the shipping industry. To end, the chapter attempts to define potential demand regions for the SAN.

Chapter 4: Proposed Facility Location Model
Chapter 4 proposes a solution methodology according to the findings from Chapter 2 and 3. It starts by justifying the architecture of the proposed model. What follows is a description of the model's locus within the location planning process. Lastly, the proposed model is presented followed by a summary of assumptions and limitations.

Chapter 5: Case Study
Chapter 5 starts by offering a preliminary of the case study, declaring more specific parameters and constraints. Thereafter the chapter discusses the operational and upkeep doctrines of the SAN through defining appropriate terms and concepts. The relevant input is presented. Ultimately, the proposed model from Chapter 4 is applied to the case study. To conclude, the results of the optimisation are analysed, the parameters and inputs tested for sensitivity.

Chapter 6: Model Validation

Chapter 6 is the final body of the research. The chapter contains the feedback from the data questionnaires from which the input for Chapter 5 is validated. The second part of the chapter is dedicated to validation the model itself by whichever means applicable.

Chapter 7: Proposed Facility Location Model

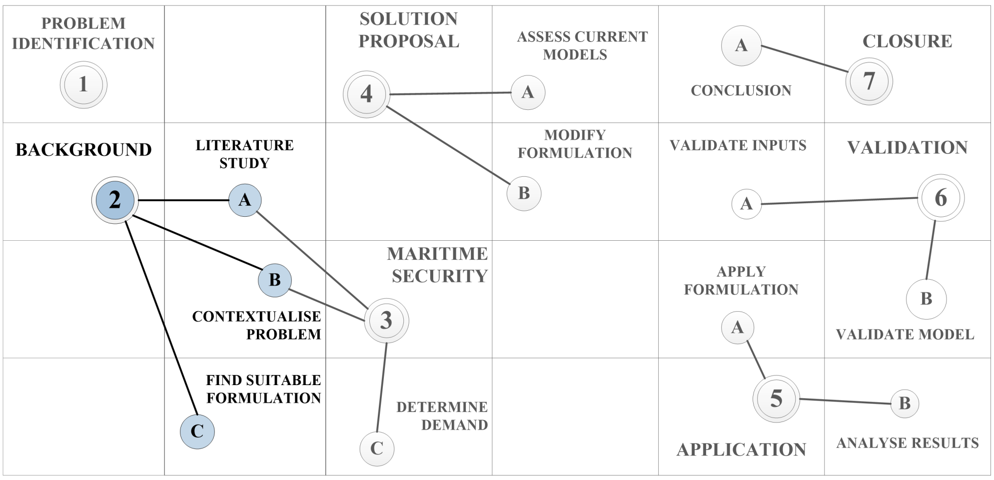
Chapter 7 reflects on the research conducted and presents the findings of the study. Consequently, the final conclusions are drawn and the central research question answered, testing the null hypothesis. The thesis concludes with managerial recommendations and recommendations for future research.

Chapter 2

Literature Study

Chapter Aim:

The aim of this chapter is to provide the necessary literature to conceptualise the problem, consequently providing the theoretical foundation for the proposed solution. The essentials of facility location, strategic management and scenario crafting are presented in relevant context to the research problem.



Chapter Outcomes:

- Conceptualisation of the problem within literature.
- Discovery of possible solution formulations.
- Introduction of scenario planning
- Identification of location criteria.

2.1 Facility Location

Decisions involving the location of facilities are critical elements in strategic planning for a wide range of private and public firms. The high construction and acquisition costs of facility location or relocation make such projects long-term investments, thus to make financial or strategic sense, new facilities need to remain in operation for an extended period of time. Consequently, the ramifications of these decisions are long lasting and far reaching, impacting numerous operational and logistical decisions. Decision makers must be sure to select sites that not only meet the objectives in the current system state, but will perform well in the uncertain future, even as the environmental factors change, populations shift and market trends evolve (Owen and Daskin, 1998, 423). Finding robust facility locations in an uncertain environment is thus an important strategic challenge.

In meeting this challenge, operations researchers have accumulated vast literature and developed a number of different mathematical models and approaches to solve problems related to facility location under uncertainty. The complexity of such problems have limited, for some time, the literature to *static and deterministic problems*. In these formulations, all inputs (such as demands, distances and travel time) are known quantities and outputs are specified as single best values, an optimal set at that point in time. While such problems have contributed to the history and development of future models and can provide some insight into the general location problem, they are somewhat obsolete in that they are unable to model the uncertainties that are inherent to real-world problems (Owen and Daskin, 1998, 423).

Consequently, research trends have shifted from simple static and deterministic models to the study of stochastic and dynamic aspects of facility location. Both stochastic programming and dynamic approaches move towards models which attempt to formalise the complexity and uncertainty aspects of real-world problems. Dynamic formulations aim to transform snapshot models (read static and deterministic) of one-time decisions into extended horizon models, temporarily capturing the aspects of real-world problems. Stochastic formulations assume that future values of inputs are uncertain and can be grouped in two approaches; a probabilistic and a scenario planning approach.

In the interest of brevity, only a basic review of the literature found on facility location is presented, attempting to lay a foundation for the subsequent sections. Thus in this section we will briefly review static and deterministic location problems, but ultimately focus on the uncertain nature of facility location by considering both dynamic and stochastic problem characteristics, expanding even further on the latter. The stochastic literature is then further divided and reviewed in two classes: that which explicitly considers the probability distribution of uncertain parameters, and that which captures uncertainty through scenario planning.

2.1.1 Static and deterministic location problems

Since the mid-1960s the study of location theory has flourished from its formal conception in 1909, when Alfred Weber considered how to locate a single warehouse so as to minimise the total distance between it and several customers (Farahani and Hekmatfar, 2009, 1). The most basic formulations can be characterized as both static and deterministic. These models take constant, known variables as inputs and produce a single solution, optimum at a certain point in time (Owen and Daskin, 1998, 425). In this section, some of the fundamental static and deterministic location problems will be reviewed, structured by the different objective functions common in each class.

1. *Median problems*: One way to measure the effectiveness of a facility location is by determining the average distance travelled by those who interact with it (supply or demand). In other words, travel time and travel distance represent the “cost” of travelling from one location to another. As travel distance increases, accessibility to the location decreases and thus the perceived facility effectiveness. This relationship holds for facilities to which proximity is desirable such as libraries, schools and emergency service centres. The location effectiveness of “undesirable” facilities such as nuclear power stations increases as the accessibility decreases, e.g. the direct opposite of conventional problems (Owen and Daskin, 1998, 426).

   An equivalent way to measure location effectiveness is to calculate the total weighted distance between demand nodes and facilities. The most popular, called the *P-median problem*, uses this measure of effectiveness.

2. *Covering problems*: For some facilities, selecting locations which minimise the average distance travelled may not be ideal. Suppose, for example, that a city is locating an emergency facility such as a fire station. The nature of the service will demand a maximum acceptable travel distance or more importantly, time. Such facilities thus require a different measure of location efficiency as the key function is "coverage". A demand is said to be *covered* if it can be served within a specified time. The relevant literature is divided into two segments, the first in which coverage is required (*set covering problem*) and the second in which coverage is optimized(*maximal covering problem*). In the set covering problem, the objective is to minimise the cost of facility location such that a specified level of coverage is obtained. Unless stated otherwise, its calculating the least amount of facilities needed at specific locations to guarantee a certain level of coverage to all customers. In many practical applications,

Decision Makers (DM) find that they do not posses sufficient resources to build facilities driven by a desired level of coverage. Hence, the maximal covering problem seeks to maximise the amount of demand covered by inputting a desired coverage distance S, whilst being given a fixed number of facilities.

3. *Center problems*: The potential infeasibility of the set covering approach mentioned above have led to the class of *P-center problems*. Such problems require coverage of all demands, but seek to locate a given number of facilities in such a way as to minimize covering distance. The p-center problem is known as the *minimax problem*, as it seeks to minimise the maximum distance between any demand and the nearest facility (Owen and Daskin, 1998, 429).

2.1.2 The P-median problem

Adding to the static and discrete literature is a set of *location-allocation problems*, which builds on basic location theory to simultaneously locate facilities where they will best interact with other facilities and demand nodes. Thus optimising flow of product or services to the customers. The P-median problem has been extensively used as a basis to build such problems related to public sector facility location-allocation modelling (Marianov and Serra, 2002, 132). The integer programming formulation of the P-median problem is as follows:

$$\text{Minimise} \left\{ Z = \sum_{i=1}^{m} \sum_{j=1}^{n} a_i d_{ij} Y_{ij} \right\} \tag{2.1}$$

Decision variables:

$$X_j = \begin{cases} 1 & \text{if potential facility is located at site } j, \\ 0 & \text{if not.} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if demand node } i \text{ is served by facility } j, \\ 0 & \text{if not.} \end{cases}$$

subject to:

$$\sum_{j}^{n} X_j = P, \tag{2.2}$$

$$\sum_{j}^{n} Y_{ij} = 1 \quad \forall i, \tag{2.3}$$

$$Y_{ij} - X_j \leq 0, \quad \forall i, j, \tag{2.4}$$

$$X_j \in \{0, 1\} \quad \forall j, \tag{2.5}$$

$$Y_{ij} \in \{0, 1\} \quad \forall i, j. \tag{2.6}$$

where

i	=	index of demand nodes
m	=	total number of demand nodes in the solution space
j	=	index of potential facility sites
n	=	total number of potential facility locations
a_i	=	demand/weight associated with each demand node
d_{ij}	=	distance between demand area i and potential facility at j
P	=	the number of facilities to be located

In this genetic formulation it is assumed that all demand points are also potential facility sites, ($m = n$), this will not be true in the scope of this thesis for reasons that will be become clear. The first set of constraints (Equation 2.2) requires that exactly P facilities be located. The second set of constraints (Equation 2.3) forces each demand node to be assigned to only one facility. The third set (Equation 2.4) allows demand node i to assign to a point j only if there is an open facility in this location, this is also known as the "Balinski" constraint. The final constraints are binary requirements for the problem variables (Marianov and Serra, 2002, 133).

Since its conception and formulation in the turn from sixties to seventies, the P-median problem has been modified or adapted to allow better "real world" implementation of specific location problems in the public sector. One such development was the introduction of the capacitated P-median problem. In this model facilities have limited capacity, hence the following constraint needs to be added where C_j is the maximum capacity of each facility:

$$\sum_{i}^{m} a_i Y_{ij} \leq C_j \quad \forall j, \tag{2.7}$$

A difficulty experienced with implementing the P-median problem is related to the distance parameter. The model assumes that travel times (or distances) do not change over any period. Travel times could vary during the day or year, on the other hand, so can demand. Therefore an optimal solution during peak demand may be suboptimal or even least optimal during off-peak periods. Faced with this rigidity of the P-median problem, Marianov and Serra (1998) introduced the concept *regret* and *minimax* objectives to determine the locations of fire stations in Barcelona. The formulation of the minimax and regret P-median problem can be found in Section 2.2 due to its association with scenario models.

Another problem related to the P-median methodology is data aggregation. Demand areas are modelled as "nodes" or "points", therefore some spatial aggregation of the demand is performed. Simply put, areas are represented by a single node or facility. This is especially true when locating in urban areas, when census tracks are numerous and need to be grouped into demand areas (Marianov and Serra, 2002, 138).

The P-median assumes facilities are similar or of a single type. Nevertheless, in real-world problems many facilities or institutions are hierarchical in nature, providing several or different levels of service. In such a hierarchical system, services are organised in levels that are somehow related to each other in the complexity of the total function. To elaborate, a medical clinic can provide an ambulance service and some level of medical treatment whereas a hospital can provide the same and higher levels of service, but they are related as mentioned (Marianov and Serra, 2002, 139).

Just as the aforementioned application requires the consideration of both location and allocation, practical applications often introduce more objectives than simply minimising cost and maximising coverage. Consequently, a class of multi-objective location models have been developed since to reflect the real-world complexity of these applications. The models and applications mentioned thus far focus on the principles of accessibility to customers. It is worthy to note that there is also a growing specialist area of research for locating obnoxious or unwanted facilities(Owen and Daskin, 1998, 431).

2.1.3 Multi-Level Facility Location

In 1973, Calvo and Marks proposed a model to locate various types of health facilities whilst allocating different types, and levels of demand, to these facilities: the model minimised distance, user costs, and maximised utilisation. The model has since been widely referenced in the literature as a "successively inclusive"[1] hierarchical relationship. Tien *et al.* (1983) argued that the approach taken by Calvo and Marks (1973) actually resulted in a "locally inclusive"[2] model. Tien *et al.* corrected the shortcomings in the Calvo and Marks model to obtain a true "successively inclusive" hierarchical location-allocation model. The following assumptions hold for such a model:

1. users go to the closest appropriate level;
2. there is no referral to higher levels after assignment;

[1]A hierarchy is said to be *successively inclusive* if a type k facility provides k level of service, and all lower levels of service, to itself and all those outside its the vicinity.

[2] A hierarchy is said to be *locally inclusive* if a facility of type k provides k level of service, and all lower levels of service, to itself but only type k service to all those outside its vicinity

3. all facilities offer lower level services

The successively inclusive model can be formulated as follows:

$$\text{Minimise} \left\{ Z = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} \sum_{h=1}^{s} a_{ih} Y_{ijh} \right\} \tag{2.8}$$

Decision variables:

$$Y_{ijh} = \begin{cases} 1 & \text{if the } h\text{th population group in area } i \text{ is assigned to area } j \\ & \text{where a type } h \text{ facility is located,} \\ 0 & \text{if no assignment takes place.} \end{cases}$$

subject to:

Let a_{ih} be the number of people in group h residing in area i and requiring order of services h. The total population in area (demand) in area i is given by:

$$a_i = \sum_{h=1}^{s} a_{ih}, \tag{2.9}$$

Tien *et al.* contributed by modifying the original constraints to the following:

$$\sum_{j}^{n} Y_{ijh} = 1 \quad \forall i, h, \tag{2.10}$$

$$Y_{jjh} \geq Y_{ijh} \quad \forall i, j, h, \tag{2.11}$$

The original formulation continues as follows:

$$\sum_{i=1}^{n} Y_{iih} = \sum_{r=h}^{s} m_r \quad \forall h, \tag{2.12}$$

$$Y_{ijh} \in \{0, 1\} \quad \forall i, j, h. \tag{2.13}$$

where additional notation is defined as follows:

s	=	total types of facilities (or services)
n	=	total number of locations
a_{ih}	=	demand in location i requiring type h facility or service
m_h	=	number of type h facilities to be located
d_{ij}	=	distance from demand area i and area j

Similar to the genetic P-median model, this formulation also assumes that all demand points are also potential facility sites. The most apparent difference is the inclusion of the h modifier to include different levels of service in the model. The first set of constraints (Equation 2.9) states that the total demand of each area consist of the sum of the different levels of service required within that specific area. The second and third set of constraints, (Equation 2.10) and (Equation 2.11) provide that each demand level h in location i is assigned to a facility of type h in location i or j whilst avoiding the possibility of assigning individuals residing in location i and requiring type h service to location j where no such service is available. Set (Equation 2.12) specifies the total number of facilities, by type, that can populate the solution space. The final constraint is a binary requirement for the problem variable (Tien *et al.*, 1983, 1129).

Tien *et al.* (1983, 1131) explicitly formulated and solved a successively inclusive model which has been widely referenced. Moreover, the zero-one integer programming formulation developed is for the most part, solvable by standard integer programming solution procedures. It is also obvious that there are potentially other hierarchical facility location-allocation formulations or models, corresponding to different hierarchical relationships in each problem. The successively exclusive property of this formulation makes it ideal for optimising the locations of facilities providing different levels of maintenance.

2.2 Facility Location under Uncertainty

In uncertain situations, the parameters are unclear and the probabilities unknown. The problems associated with risk situations are known as *stochastic and dynamic optimisation problems*; the goal being to optimise the value of some objective function. Hence, the goal of both stochastic and dynamic optimisation is to find a solution that will perform well under any possible realisation of the future, i.e. random parameters. Performance varies from application to application and choosing an appropriate measure is an important part of the modelling process (Snyder, 2006, 538).

The majority of location theory research can be drawn from the aforementioned models (see Section 2.1.1), their applications and extensions. As mentioned, these models do not capture many of the characteristics found in real-world location problems, especially the factor of uncertainty. Consequently, decision makers must be sure to select sites that not only meet the objectives in the current system state, but will perform well in the uncertain future, even as the environmental factors change, populations shift and market trends evolve. As Owen and Daskin (1998) mention in their review, the "strategic nature of facility location problems require that any reasonable model considers some aspect of future uncertainty." It is for this reason that the focus of this section will be on the explicit uncertainties inherent to location problems due to unknown inputs, hence stochastic and dynamic location models.

2.2.1 Dynamic location problems

In 1968, Ronald Ballou published the first paper that recognised the limited application of static and deterministic location models. Consequently, Ballou used a series of static deterministic optimal solutions to solve the dynamic problem (Owen and Daskin, 1998, 432). This approach was found to be suboptimal in 1976 by Sweeney and Tatham (1976) who improved on Ballou's solutions by extending the set of potential location sites. To elaborate, Ballou (1968) simply produced an optimal warehouse location for consecutive periods using static deterministic models. One would then choose the optimal sequence of these locations to minimize total cost of operation and relocation. Sweeney and Tatham (1976) argued that a configuration which yielded a second best static solution in each period could possibly yield the long-run optimal location since no relocation is necessary, but is overseen as only optimal solutions were considered by Ballou. Sweeney, Tatham and Ballou allowed for frequent facility relocation, but neither considers construction time nor cost.

Owen and Daskin (1998, 435) acknowledge that the difficulty in solving dynamic facility location problems arises from the uncertainty of future conditions. Even the length of the established horizon is a problem which is ignored in most formulations. They argue that the best way to manage uncertainty in dynamic problems is to postpone the decision making as long as possible. Since the first period decisions are the only ones that take immediate effect, Owen and Daskin (1998) claim that the goal of dynamic location planning should be to find an optimal or near-optimal first period solution for the problem over an infinite horizon. Simply put, determine the optimum starting location with near-future certainties, then collect information and update forecasts as time advances to determine when to expand or relocate.

2.2.2 Stochastic location problems

The dynamic models described previously (Section 2.2.1) attempt to place facilities in optimal or near-optimal locations over a specified time horizon. While capturing more of the uncertainty inherent in real-world problems than static and deterministic formulations, these models assume that input parameters are known values that change deterministically with time. This section will review real-world location problems of a stochastic nature.

The stochastic literature is divided into two classes according to Owen and Daskin (1998, 435): that which explicitly considers the probability distribution of uncertain parameters, and that which captures uncertainty through scenario planning, consequently, requiring that any reasonable model consider some aspects of future uncertainty. Hence research on stochastic location problems can be broken down into two primary approaches:

· Probabilistic approach; and

· Scenario planning approach

In both cases, any number of system parameters might be taken as uncertain and even relatively certain parameter might be presented as a probability, such as construction costs or travel times. The objective is to determine if the location will be robust enough to perform well under a number of possible parameter realizations. Probabilistic models explicitly consider the probability distributions of random variables whilst scenario planning models consider a generated set of possible future variable values (Owen and Daskin, 1998, 435).

2.2.2.1 Probabilistic Models

As mentioned in the foregoing paragraph, some models capture the stochastic aspects of facility location through explicit consideration of the probability distributions related with random modelled quantities. These distributions can be incorporated into standard mathematical formulations, or in a queueing framework (Owen and Daskin, 1998, 435).

The scope of this thesis does not permit the additional complexity and the time consuming collection of data that accompanies probabilistic models, hence such inputs have purposefully been circumvented, as has been the vast literature. Hence more focus will be given to the scenario planning approach. Although probabilistic literature has been excluded from this project, it is worth mentioning due to the relevance and stake it holds in facility location literature.

2.2.2.2 Scenario Planning Models

Scenario planning is a method in which decision makers qualitatively deal with uncertainty, by specifying a number of plausible future states, derived from the present state with consideration of potential major events (Owen and Daskin, 1998, 431). An example would be the High-Low Road analysis usually adopted by small businesses, where predicted best and worst-case figures are used to model future states.

Ideally the objective is then to find solutions which will perform well under all scenarios. In some applications scenario planning replaces forecasting as a way to evaluate trends and potential changes in the business environment. Firms or governments can then develop strategic responses to counter a range of changes, thus preparing themselves for the uncertain future.

From a purist perspective, the goal of scenario planning is to derive and specify a set of scenarios, which represent the possible realisations of unknown problem parameters. Owen and Daskin (1998, 442) list three approaches to incorporating scenario planning into location modelling:

· optimising the expected performance over all scenarios,

· optimising the worst case performance, and

· minimising the expected worst case regret across all scenarios.

The above mentioned methods are focused on regret-based approaches. In economic terms it would translate into minimising the opportunity cost of each scenario. The regret associated with a scenario is calculated by comparing the performance of the optimal locations for the scenario (if the scenario would be realised for certain) with the performance of the compromised locations when the scenario is realised. To demonstrate the concept, consider if a company knew for certain that their target market will shift to a new emerging demographic group, they could locate their facility accordingly (read optimally). As the extent of this new demand is uncertain, the decision makers can decide to compromise by locating it closer to their current demand whilst partially being able to service the emerging demand. Now the company can calculate the regret by estimating sales if the new demand did emerge and the facility was optimally located versus the projected sales if the facility was located at the compromised position. Using a regret-based objective thus allows the evaluation of compromising solutions against all other optimal alternatives obtained under data certainty, thus allowing us to test the robustness of the solution. Some papers use this measure in objectives is relation to the probability of realization while others assume that all scenarios are equally likely (Owen and Daskin, 1998, 442). The formulation for the minimax P-median is as follows:

$$\text{Minimise} \qquad \{ M \} \tag{2.14}$$

Decision variables:

$$X_j = \begin{cases} 1 & \text{if potential facility is located at site } j, \\ 0 & \text{if not.} \end{cases}$$

$$Y_{ijk} = \begin{cases} 1 & \text{if demand node } i \text{ is served by facility } j \text{ under scenario } k, \\ 0 & \text{if not.} \end{cases}$$

subject to:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\frac{a_i d_{ijk} Y_{ijk}}{W_k} \leq M \quad \forall k, \tag{2.15}$$

$$\sum_{j}^{n} X_j = P, \tag{2.16}$$

$$\sum_{j}^{n} Y_{ijk} = 1 \quad \forall i, k, \tag{2.17}$$

$$Y_{ijk} - X_j \leq 0, \quad \forall i, j, k, \tag{2.18}$$

$$X_j \in \{0, 1\} \quad \forall j, \tag{2.19}$$

$$Y_{ijk} \in \{0, 1\} \quad \forall i, j, k. \tag{2.20}$$

where additional notation is defined as follows:

k	=	index of possible scenarios
a_{ik}	=	demand at node i under scenario k
W_k	=	the total population in scenario k
d_{ijk}	=	distance from demand area i and facility at j under scenario k

The first constraint (Equation 2.15) is directly related to the objective function, that is finding the smallest maximum average travel time possible when all scenarios are evaluated. The left side of the constraint represents the demand weighted average travel time (one for each scenario) that will be achieved in the corresponding scenario. The objective of the model is to minimise M, which is the same in each constraint. That is, the model aims to find a set of location that minimises the largest total travel time or distance in each scenario. The rest of the constraints are of a similar nature to the constraint set of the classic P-median problem found in Section 2.1.1 (Marianov and Serra, 2002, 137). If the regret objective is used, constraint (Equation 2.15) is modified, by deducting Z_k, to the following:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\frac{a_i d_{ijk} Y_{ijk}}{W_k} - Z_k \leq M \quad \forall k, \tag{2.21}$$

Z_k is the optimal objective found when P facilities are located optimally in each scenario individually. Its value is found by applying the original P-median formulation to each scenario, as mentioned, individually. The unknown variable M represents the regret evaluated over all scenarios (Marianov and Serra, 2002, 137).

The scenario approach has two main drawbacks. One is that identifying, crafting and assigning probabilities to scenarios is a daunting and difficult task. The second disadvantage is the small number of possible scenarios usually generated for computational reasons, but this limits the range of future states under which decisions are evaluated. Scenarios do provide, however, more tractable models and has a further advantage of allowing parameters to be statistically dependant. Such dependability unusually occurs when parameters are described by continuous probability distributions. Dependence is necessary to model reality since entities rarely function in isolation, for example, demands are often influenced by geographical regions and time periods whilst costs are often influenced by the effect suppliers have on each other (Snyder, 2006, 538).

2.3 Strategic Management

This section aims to review the basics of strategic management whilst continuously shifting the literature related focus to the application thereof in the public sector. Consequently, the word “company” or “organisation” will be used synonymously with “agency” to allow for the dual interpretation of the literature, applicable to both private and public literature until stated otherwise. The term 'operating environment' will be used to describe business environments or the public sector equivalent and should not be confused with a physical environment as used in Chapter 3.

2.3.1 Basic Strategic Management

Crafting and implementing strategy form the core of management functions. Few affect company performance more fundamentally than the management of the company's long term direction. Indeed, to quote Thompson *et al.* (1996):

> *Good strategy and good strategy execution are the most trustworthy signs of good management.*

Strategy is grounded in the array of tangible and intangible movements that management depends on to produce continued successful performance. In other words, it is management's game plan for strengthening the organisation's position, pleasing customers or constituents, and achieving performance objectives. To give some brief background on the concept of strategic management, Thompson *et al.* divides the strategy making and implementing process into five managerial tasks.

1. Forming a strategic vision of what business the company will be in, effectively infusing a sense of purpose and providing long-term direction.

2. Converting the strategic vision and mission into measurable objectives and performance targets.

3. Crafting a strategy or game plan to achieve desired results.

4. Implementing and executing the chosen strategy efficiently and effectively.

5. Evaluating performance and initiating adjustments in long-term direction, objectives and strategy.

Both strategic and financial objectives should carry top priority. However, companies under pressure to improve near-term financial performance sometimes elect to sacrifice or postpone strategic moves that possibly could have strengthened their competitive position over the horizon. Companies that regularly pass opportunities to strengthen its long-term competitive position in favour of better financial gains risks diluting its competitiveness and losing momentum in its market share. By no means does this make short-term planning irrelevant.

An organisation needs both long and short-term objectives. Long-term objectives serves two purposes. Firstly, it forces managers to take actions early (now) in order to achieve objectives in five or more years. An example would be an attempt to double some performance output, say customer service levels (external) or the amount of employees (internal), over the next five years. Managers cannot wait until the third or fourth year to improve customer service or create more employment opportunities. Secondly, having explicit long-term objectives encourages managers to weight the impact of current decisions on performance in the long run. Short term objectives spell out the immediate and near-term performance results to be achieved. They indicate the speed and which management wants the organisation to progress. These objectives can be identical to long-term goals when an organisation is already performing at the targeted long-term level. If a company has an objective of 15 percent profit growth per annum and is currently achieving this growth, then the long and short term objective coincide. Short term objectives serve to elevate organisational performance when long-range targets cannot be met in one year, thus serving as steps or milestones (Thompson *et al.*, 1996, 35).

An organisation's strategy should evolve over time. Owen and Daskin (1998) agree with Thompson *et al.* (1996) that it is seldom possible to plan any company's strategy in great detail due to the inherent uncertainty the future brings. It is therefore not practical to plan great detail and even less so over long periods without changing it. Reacting and responding to internal and external events is a normal part of the strategy-making process. This view will be reiterated by Ring and Perry (1985) and Sunter (2012) in Section 2.3.3 and 2.4 respectively. Thompson *et al.* continues that the dynamic and partly unpredictable character of competition (or governmental policy), changing trends in customer needs and expectations, unplanned fluctuations in costs and countless other events can make the whole or parts of the strategy obsolete. This is why the task of crafting strategy is never ending, resulting in most successful strategies being a blend of its intended strategy and its adaptation to unplanned developments (Thompson *et al.*, 1996, 36).

Operating environments will constantly reveal opportunities and developing threats, both having influences on strategy, pointing to the need for strategic action. Consequently, a company's strategy should aim to, or be in a position to, capture such opportunities whilst defending itself against current and future external threats. External threats could, in the context of public agencies, be a decrease in budget. In the same breath, pursuing opportunities without the organisational competencies and resources to take complete advantage of it is not advisable. Likewise, weaknesses make certain strategies risky or even out of the question (Thompson *et al.*, 1996, 49).

Company culture is the combination of an organisation's policies, practices, traditions, philosophical beliefs and ways of doing things. A company's strategic actions typically reflect these traits and managerial values. In some cases, company culture can dominate the choice of strategic moves (Thompson *et al.*, 1996, 50). One such affected strategy is called vertical integration. Vertical integration extends a company's competitive scope within the same industry, expanding its range of activities backward, into supply sources, or forward, toward end users of the final product. Thus, if a manufacturer moves to acquire some supply capability it essentially stays in the same industry as before, except now the business has two production stages in the industry's value chain system. Similarly, if a manufacturer elects to open retail stores to sell its product, it remains in the same industry although its competitive scope has extended forward in the chain. Horizontal integration will then, by definition, be an extension into non-related industries effectively diverting risk and opportunity to another industry (Thompson *et al.*, 1996, 142).

The only good reason to invest resources into vertical integration is to strengthen a company's competitive position. In other words, unless vertical integration produces sufficient cost savings or competitive advantage, it has no real remuneration. Integrating backwards generates cost savings when the supplier has sizeable profit margins or the item being supplied is a major cost component. Vertical integration has some substantial drawbacks though, fully integrated companies tend to adopt new technologies slower than partially or non-integrated companies. Also, it locks the company into sourcing from its in-house capabilities although outsourcing could later be less costly.

Outsourcing is often quicker and cheaper than vertical integration, allowing a company to be more adaptive to the ever changing business environment. Any of the advantages of vertical integration can be captured and many of the disadvantages avoided by entering long-term partnerships with key suppliers (Thompson *et al.*, 1996, 144).

Thompson *et al.* does well to cover most of the basic literature on strategic management and serves well as an introduction to the field. Unfortunately he fails to explicitly differentiate between the strategic environments in the private sector, and that of the public sector. In Section 2.3.2, Poister and Streib (1999) will reiterate many of the concepts mentioned by Thompson *et al.* but in a context more applicable to strategic management in the public sector.

2.3.2 Strategic Management in the Public Sector

A strong strategic management capability is essential to any governmental agency because it provides both short and long-term direction relative to its environment (internal or external), which is assumed to be ever changing. Changes in societal (read customer or constituent) needs, political trends, inter-governmental relations, financial conditions and organisational expectations are likely to influence the responsibilities and resource requirements of governmental institutions. Agencies and institutions as such will be required to asses their own managerial capability, power and organisational structure and leadership if they intend to successfully implement strategic management. A strategically managed public agency is one in which the strategic agenda guides the budgeting, performance measurement, human capital development and program management among other processes. It is essential that key actors are kept involved and the strategy is communicated widely within the organisation and to external constituencies (Poister and Streib, 1999, 309).

For strategic management to be successful, there must be a shared commitment to the values, mission, and vision both within the governmental unit and among the relevant external stakeholders. Thus, an important part of strategic management, in both the public and private sector, necessitates developing and refining a clear sense of the values, mission, and vision whilst working to build and maintain common ownership of these. Those responsible for strategic management must ensure that relevant administrative systems (budgeting and financial) are able to facilitate the implementation of strategic plans and to reinforce the strategy throughout the governmental unit (Poister and Streib, 1999, 312-313).

Poister and Streib recommend the following guidelines, based on success with similar programs, to improve strategic management in the public sector:

· *Supplier Relationship*: Forge more productive relationships with suppliers to improve the quality of service to the agencies, resulting in decreased shipping time and improved accuracy.

· *Injured Employees*: Pay careful attention to the needs of injured employees and implement an aggressive return-to-work programme to substantially reduce the number of employee workdays that are lost due to on-the-job injuries.

· *Common Ownership*: Whereas strategic planning was initially limited to top management, lower level managers and external stakeholders should be included in the strategic planning, promoting common ownership of the strategy.

· *Motivational Themes*: Introduce motivational themes for strategies such as "maintenance first" or "Beating Xerox". These can inspire employees and instil a sense of purpose.

In response to the growing need for public accountability, financial constraint, increased legislative oversight, improved performance and an orientation tuned to customer service, public managers have been submerged in the idea of managing for results. Poister and Streib (1999, 323) argues that it is impossible for public agencies to manage for results in the short or long term without a well developed capacity for strategic management. Certain constraints do apply more specifically to the public environment limiting effective short or long term management capabilities, irrelevant of the above mentioned guidelines, and will be discussed in the next section.

2.3.3 Distinctions and Constraints

Ring and Perry (1985) argue that strategic managers in public and private sectors operate in fundamentally different environments that generate distinctive constraints on their behaviours and choices. These variations are critical to understanding the differences between the two strategic management processes. Perhaps the most vital of these differences stems from organic law[3]; constitutions, which divides policy formulators from policy implementers through its effort to maintain a separation of power. Thus legislatures initiate, but seldom implement policy. On the other hand, executive agencies can often only pursue legislatively authorised objectives. It is hard to imagine a situation where top management in a private sector organisation are unable or prohibited by company policy from engaging in strategy implementation, or only external stakeholders or directors can make major strategic decisions. On

[3]An organic law is a law or system of laws which forms the foundation of a government, corporation or other organization's body of rules. A constitution is a particular form of organic law for a sovereign state.

the contrary, literature on strategic management promotes active involvement of all relevant parties throughout the process of policy implementation (Ring and Perry, 1985, 277).

Another constraint unique to public sector strategic management arises out of its characteristic openness to the external environment. Constituents of the public sector have direct, constitutionally or legislative based avenues to access or influence strategy makers. Publicly available transcripts of governmental meetings and public participation on most legislative matters would be an example of such an influence. These constituents demand, and mostly receive the attention of their elected representatives. Public managers that fail to pay attention to such constituents run the risk of inviting political repercussions. Private sector leaders or boards of directors, on the contrary, may ignore most external stakeholders' demands for direct input with little risk to their careers or to their organisations credibility (Ring and Perry, 1985, 277).

Finally, the public sector has established a number of formal processes in the from of ombudsmen and committees, to monitor the conduct of public officials, to an extent rarely found in the private sector. This brief outline of some of the factors influencing strategic management in the public sector serves as introduction and basis for the constraints outlines by Ring and Perry (1985) that are generally not accounted for in discussions of strategic management processes. They are listed as follows (Ring and Perry, 1985, 279-281):

1. *Policy Ambiguity*: The primary reason for the lack of policy clarity in the public sector stems from the need to merge multiple and often conflicting objectives in order to gain passage of legislation. Contrary to the majority of literature on strategic management, Ring and Perry argues that a clear, unambiguous expression of strategy can produce at least two counter-productive consequences. First,a clearly expressed strategy may serve as a device for mobilising political opposition. Secondly, a clear directive may, in the words of Mintzberg (1978), permit "bureaucracy to run like an elephant", referring to strategy formulation during the Vietnam War of 1965 - 1968. Mintzberg concluded that another strategy that gets it moving may be no more than a mouse, but once under-way there is not much stopping it. In other words, clear and precise policy statements may lead public executives to believe there is less need to exercise caution and discretion. This tendency can be particularly troublesome for public decision makers, given the autonomy of service employees and their sensitive societal mission. Ambiguity in strategy therefore may be an asset in many public organisations.

2. *Openness to Public*: The role media play is frequently cited as one of the major differences in the professions of public and private managers.

Former high ranking government officials in the U.S. state that they have found media coverage so intense, compared to their experiences in the business world, that policy had a tendency to be exposed earlier to public scrutiny, to be dissected more thoroughly, and be dismissed before it ever got of the drawing boards.

3. *Attentive Public*: The openness of public sector organisations to the media is not defined exclusively by the attention of the media. Public sector managers must pay much more attention to a diverse public consisting of a variety of competing interests, internally and externally. It thus becomes clear that strategic managers in the public sector must take into account a wide range of stakeholder interests. In addition, these stakeholders are likely interpret the results of such a process differently, often reaching conclusions that will be difficult to reconcile. Poister and Streib (1999) expands on this point by Ring and Perry (1985) that conflict resolution, influence and persuasion and are the tools of a public manager rather that authority and such.

4. *The Time Problem*: Another major factor limiting public strategic management processes is time. Firstly, the tenure of public officials; that is, their length of stay in with an agency or organisation. The second involves time constraints that are imposed legislatively or by court. To summarise, time constraints for public organisations tend to be generated by legislatures, funding parameters or the tenure of public officials. Time constraints in the private sector, on the other hand, tend to be decided or defined by the market. An example of the consequences of such a constraint would be when the time needed to implement a policy exceeds the tenure of the public managers, consequently the new officials have to complete the implementation process, possibly causing a lack of coordination and adding more time to the process.

These aforementioned propositions carry a number of important implications, most notably, that strategic management in the public sector may be extremely difficult. Under such circumstances, it is likely that public sector performance will be found inadequate if judged against a standard strategic management model. However, judged against standards set in the public sector, different conclusions might be drawn. The performance criteria can then be qualitatively analysed and compared to those from the private sector. Another implication of the distinctive constraints are that they require a significantly different set of behavioural responses from public strategic managers (Ring and Perry, 1985, 281).

The constraints set out above appear to be more easily managed by very-short-term or incremental processes than those that are rigidly planned over an extended period. To summarise at this point, given the previous arguments regarding policy ambiguity, open and intense public influence and the efficiency loss associated with disconnected tenure policy, public organisations can be characterised as low on deliberate strategy and high on emergent and unrealised strategy. Consequently, attention to emergent rather than intended strategies may be a key feature of successful management in the public sector. Ring and Perry (1985, 283-285) recommends the following guidelines to improve strategic management in the public sector:

· *Maintain Flexibility*: If the strategy process tends to be reactive and more exposed to external influences, flexibility, adaptability and a peripheral outlook appear to be required from public managers. Such managers should avoid becoming immersed in the details of policy but should instead focus on managing the policy agenda. Due to the likelihood of intense media scrutiny, public managers and their legislative officials should avoid making public statements that prematurely commit themselves, or their agencies, to a given set objectives. Successful adaptive behaviour appears to be associated with the ability to interpret the law "creatively" and to act quickly and accordingly. Finally, it seems likely that successful managers will avoid using standard or preprogrammed responses and procedures as control mechanisms.

· *Wielding Influence, Not Authority*: Due to the probability that many key actors in any public strategic management process will be external to the central organisation implies that the exercise of influence is likely to be more critical than the wielding of authority. The public manager must cope with confrontation without being confrontational and posses the capability to convince those opposed to any planned policy

· *Minimising Discontinuity*: As mentioned earlier, strategic management in the public sector entails the management of discontinuity. Political relationships are unstable, political executive tenures can be brief and agendas can change constantly. Successful public managers act to minimise discontinuity and bridge the gaps that it leaves in its wake. This ability will require managers, upon appointment, to "land running" and quickly adapt and give attention to projects that were initiated in the previous tenure.

The propositions presented in this section reflect some of the unique aspects of strategic management in public organisations but may also apply to strategic management in the private sector in some context. To conclude, authors Ring, Perry, Poister and Streib agree that there are fundamental differences between strategic management in the public sector and in the private sector. Both articles propose conforming guidelines to improve such management strategies in the public sector. Ring and Perry propose that leaders in the public sector should develop outward looking, short-term strategies by preparing for the most probable external influences.

This view aligned with a component of strategic planning, namely scenario planning. A publication by Chantell Ilbury and Clem Sunter, called *Socrates & The Fox*, describes the strategic mentality of modern organisations. The following excerpt from their book is the answer from the Fox to Socrates's question: "why are you what you presently are?", after the Fox was not concerned nor surprised by Socrates's sudden intrusion into its territory.

> *My choice of parents was beyond my control, as was my date of birth. But what has been within my control since then has been to use my strengths instinctively to cover for my weaknesses. I am small and therefore vulnerable, but I am agile and have keen senses. I know my limitations, I know the risks, but I also grab opportunities as they arise. I can adapt to the changes in the environment, and, man, have there been some big changes recently! As far as I know, you're the first person to have ventured into this grove. You have to accept change, and change with it. Call it foxiness that keeps me alive.*

2.4 Mind of a Fox

Chantell Ilbury and Clem Sunter[4] have developed a scenario planning technique that presents different scenarios in a matrix, rather than listing them individually. This allows the logical connection between the scenarios to be more easily visualised. The choice of the two axis that form the matrix is crucial, these should be the real driving forces for each scenario. The other modifications they have made to the scenario process are to identify "flags" which indicate movement towards one specific scenario (quadrant); and then, attach a subjective probability to each scenario based on the tendencies of the flags. The flags are constantly monitored to determine the state of the matrix and to adjust the probabilities of all scenarios as soon as a flag is raised.

To better explain both the matrix method and the concept of flags, a scenario developed by Sunter (2012) will be used as an example throughout this section. He named this specific scenario matrix "The Global Tightrope", which illustrates four possible scenarios (Figure 2.1) likely to unfold, according to the

[4]Mr. Sunter was awarded an Honorary Doctorate by the University of Cape Town for his work in the field of scenario planning. He was also voted by leading South African CEOs as the speaker who has made the most significant contribution to, and impact on, best practice and business in South Africa. In 2006, he was invited to give a scenario presentation at the Central Party School in Beijing - a rare privilege for a foreigner.

various drivers and flags, following the 2008 financial crash. Firstly, the two axis (drivers). The horizontal axis describes the rate of economic recovery as a driver with U denoting a slow and V denoting a quick economic recovery. The top of the vertical axis denotes a global effort and the bottom a world that is becoming increasingly divided.

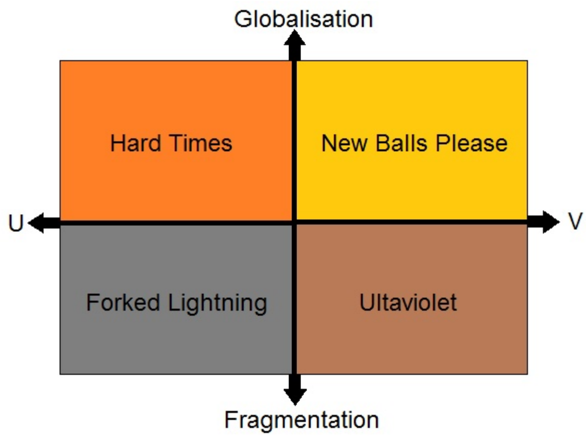


Figure 2.1: Scenario Game Board example.

The interaction between these two axis (drivers) yield four possible scenarios according to Sunter (2012):

1. The first quadrant is "Hard Times", a scenario of conventional global recession, i.o.w. slow economic recovery for everyone where unemployment rates remain high for much longer than anticipated. China and India are not spared as their dependencies on the global markets have a domino effect on their economies. Asset prices (property and equities) decrease, allowing less to be borrowed to spend. The downward spiral is reinforced by plummeting commodity prices except for gold and perhaps platinum, which do well in the uncertainties around paper currencies and assets. This not an infinite state and recovery will be under way at some stage returning the world to the top right-hand quadrant.

2. The second scenario is labelled "New Balls Please" where global effort beats the current economic hurdle but the future market is very different in its revived form, i.e. making an omelette from broken eggs. Resources will be considered limited as the East and West skirmish for economic supremacy. It is a scenario driven by the global conversion to free market economics and the continuous rise of China and India. Inflation and interest rates remain low whilst the effect of conflict zones are negated by globalisation. This scenario envisions the centre of the world economy

moving East, meaning the Western institutions will have to adapt and the G8 will become the G10 with the addition of China and India as new members.

3. "Ultraviolet" is a divided world where emerging economies experience short term recovery whilst advanced economies maintain a slow growth burdened by debt. In this scenario a number of countries revert to old-style Socialist policies (South America) and become more nationalistic about the resources they possess (Russia). There will be economic momentum as the two most populous nations on earth (India and China) continue on through their industrial revolution. The emergence of more "failed states" make investors wary whereas they would invest anywhere in the New Balls Please world state.

4. In the final scenario named "Forked Lightning" a confluence of negative events takes place in both the political and economic arenas resulting in a repeat of the early 1930s when the Crash of 1932 eclipsed the Crash of 1929. Potential triggers could be an act of nuclear terrorism in a Western city, a major war in the Middle East and the consequences for US and Russian relations, or a financial meltdown in China followed by global unrest. Recovery from Forked Lightning proves slow as business confidence has to be rebuilt from nothing. Following the Crash of 1932, stocks on Wall Street only recovered pre-1929 values 20 years later.

The critical difference between "Forked Lightning" and "Hard Times" is the compromise of globalisation in the former due to political and military events. The main threats to "New Balls Please" are global warming, a growing scarcity of raw materials and the consequential rise in inflation rates or a new global health epidemic.

In the beginning of 2012, Sunter set the probability of "Ultraviolet" at 40%, making it the most probable scenario over the next 5 years at that time. One flag that would indicate a move to "Hard Times" is a dip in China's economic growth rate below 6%. Many emerging and advanced economies, such as Germany and Australia, rely on the continued success of China. Sunter gave "Hard Times" a 30% probability which is lower than "Ultraviolet" as it was the most probable alternative should China witness a decrease in economic growth as mentioned. The flags for "New Balls Please" were a decline in unemployment in the US to under 6% and a general drop in national debt to GDP ratios amongst advanced economies. Unemployment in the US is still at a historic high of around 9,5% and debt ratios continue to climb as governments have only now begun to decrease their budget deficits, resulting in a 20% probability of "New Balls Please". The principal flag for "Forked Lightning" is a rapid increase in the 10-year US Government Bond rate above 5%, indicating a loss of faith in the dollar as an reserve currency. Other flags are a default of a sovereign European state, a trade war erupting between the West and East, a destabilising conflict in the Middle East or Korea. "Forked Lightning" was assigned a 10% probability as none of the aforementioned flags were up at the time (Sunter, 2012, 14).

Flags are monitored constantly and the probabilities are adjusted as certain flags go up or down. There are other flags and scenarios excluded by the planners as they are not thought of at that exact moment, but the matrix is dynamic in itself as the axis can be replaced by new drivers as they emerge and the quadrants with new scenarios.

2.4.1 Flags

As a more specific example of the use of flags in scenario planning, a short extract from a conversation Sunter had with one of his colleagues, Pierre Wack[5], in September 1989 will suffice. Pierre apparently asked Sunter "Do you know that two flags have gone up on Japan which suggests its imminent demise?" Back in the 1980s, Japan was destined to be the star of the 1990s with average economic growth of 7% per annum for two decades leading up to 1990, much like the situation of modern China. Pierre answered his own question:

> *"The first flag is declining golf club membership in Tokyo. The Japanese are golf fanatics and if they are resigning from the clubs, then something is happening to their disposable income which is not captured by the media. The chances of the economy hitting the wall in the short term have gone up sharply."*
>
> *"The second flag is the demographics of Japan. It is a rich, ageing society. That does not bode well for Japan's export competitiveness; its domestic spending patterns except in the area of health care; and the amount of money that has to be set aside by the government to care for the elderly."*

The second flag multiplies the effect of the first in that it is a long term influential one, indicating that a very long financial recovery or almost flat growth rate will ensue. Three months after this specific conversation, the crash occurred and Japan's economic growth over the last 21 years has averaged 1% per annum (Sunter, 2012, 151).

[5]Pierre Wack (1922-1997) was an oil executive who was the first to develop the use of scenario planning in the private sector, at Royal Dutch Shell's London headquarters in the 1970s. Through his scenario approach he was able to anticipate not just one Arab-induced oil shock during that decade, but two.

The relevant demographic flag today pertains to Europe; the population is getting older and in some countries like Italy, the population is actually declining; not ideal for economic prospects of stock markets. Add to that another short-term flag of European governments over-borrowing and possibly following in the footsteps of Greece. In China, consequences of the one-child policy since 1978 is set to fully come to light in the next 30 years. In the words of Sunter (2012, 152), “It might be the first nation to grow old before it gets rich.”

2.4.2 Black Swan Events

A Black Swan event is a term used to describe a low probability catastrophe. The term originated from an ancient Western conception that all swans are white referring to an improbable event. Ironically, the discovery of black swans in Australia in the 17th Century altered the term to suggest an exception to the rule or the existence of the improbable. The relevant theory was described by Nassim Nicholas Taleb (2008) that many scientific discoveries and events, that dramatically altered the course of history, are Black Swans. He narrates the success of Google, the rise of the Internet, the personal computer, World War I (resulting in World War II) and the terrorist attacks of 9/11, as examples of Black Swans, each demonstrating three principal characteristics (Taleb, 2007):

· its unpredictability;

· its substantial impact in which the severity of the event will be inversely proportional to its expected frequency: the so-called 10-year flood will be more frequent than the 100-year flood, and the 100-year flood will be more devastating;

· and after it has occurred, the philosophical (human) desire to make it appear less random and more predictable than it was.

Sunter (2012, 55) believes the threat for another “Black Swan” event is still there, because according to him the world has not become a friendlier place since the 9/11 attacks on the World Trade Centre in New York. Many advanced economies are hindered by unemployment and debt as they recover from the financial crash of 2008. Emerging economies like China have food price inflation, environmental destruction and a potential property bubble plaguing their progress. Hard times generally increase bitterness among ordinary people, opening the door to future divisions or conflict. The flags for the emergence of a more dangerous world are a deterioration of the economic relationship between the West and East, as power shifts from the former to the latter; a global scramble for the remaining resources as fuel, water and metals become scarcer (read scramble for Africa) and a complete loss of faith in the Dollar as an reserve currency, leading to another financial crash. A conflict or regime change in the Middle East could have global repercussions. The flags proposed by Sunter (2012, 55) indicating a shift to a friendlier world are a quicker global economic recovery and greater international effort to prevent nuclear proliferation.

Natural disasters can also be classified as "Black Swans" as they alter future scenarios dramatically. 2012 saw floods in Australia and earthquakes in New Zealand and Japan. Add in the impact of the tsunami, which followed the Japanese earthquake and the subsequent radiation leaks from the damaged nuclear reactor, on the long term health of the Japanese population. Japan represents 10% of the global economy and plays a crucial role as end-product supplier in the global manufacturing industry (Sunter, 2012). In therms of the global economy, the probability of a black swan scenario, namely a double dip of the financial crisis where the second is even bigger than the one of 2008, is flag dependent on the defaulting of a major sovereign state, specifically Spain or Italy (Sunter, 2012, 156).

A deadly strain of flu could spread and have a lasting effect on the world population. An example would be the genetic mutation of the H_5N_1 bird flu created in Rotterdam. This highly infectious influenza kills 60% of people exposed to it. Although this specific strain is safely contained, it shows that such a strain is possible and given the opportunity, nature could produce something similar. With seven billion inhabitants, the majority living in cities or directly connected to metropolises via effective transport, a global epidemic is always possible, however unlikely (Sunter, 2012, 160).

2.4.3 The Global Tightrope

As mentioned in the example from Section 2.4 (Mind of a Fox), the two most probable scenarios were "Ultraviolet", portraying a world where emerging economies grew three times faster than advanced economies hindered by debt; and "Hard Times", a future of communal low economic growth. The deciding flag was China's annual GDP growth. If it stayed in the 8-10% range, the world was still in "Ultraviolet"; and if it fell below 6%, "Hard Times" will ensue. In the previous example China's economic prospects received the benefit of the doubt, consequently according a 40% probability to "Ultraviolet" and a 30% probability to "Hard Times".

Sunter (2012) believes that it will become increasingly difficult for China to continue to grow at its current pace, for three reasons: the likelihood of an economic slowdown in Japan, which is a major trading partner; the continued rise in the price of oil as instability and unrest spread to other OPEC (Organization of the Petroleum Exporting Countries) regimes; and the possible internal unrest in China itself as a result of the 15% food price inflation. Europe can also effect China's growth as 38% of China's GDP are exports and exporting into a financially stressed Europe can take its toll. If the property bubble bursts and municipalities default on their loans, China can be sure to see a decline in economic growth. If China experiences an economic growth of less than 5%, all countries which supply China with resources will be affected (Sunter, 2012, 158). European debt crises and the US budget deficit has not gone away and the unrest in the Middle East is unprecedented in the number of countries involved. The biggest event for another major war is if Iran gets involved in some conflict and closes the Strait of Hormuz (Sunter, 2012, 159), removing roughly a quarter of the world's oil (40% of South Africa's consumption) from the market (Talmadge, 2008). This could be triggered by the escalating military situation in Syria or an pre-emptive strike by Israel, consequently forcing Russia, China, NATO and the US to intervene and secure their oil supplies.

These flags, coupled with the rise of red flags (flags indicating a Black Swan event), resulted in the reverse of probabilities between the two most likely scenarios. This example demonstrates how flags are constantly monitored and probabilities adjusted os certain flag go up or down.

There are always unscheduled events that emerge at the most inconvenient time to disrupt careful planning. In the futures trade they are called "unknown unknowns" or things planners don't know they don't know. Thus every scenario should be resilient and flexible enough to cope with change. An example would be the acquisition of an amphibious ship for the SAN and hence the African Union (AU). Planning for an unknown future could be to involve other African countries in the design requirements so that the SAN could sell or lease the vessel to another African navy when it cannot operationally maintain it due to some "unknown unknown" circumstances.

2.5 Decision Making Models

Facility location is a typical multi-criteria decision making (MCDM) problem in which subjective preference between criteria play a key role in the final decision (Yang and Lee, 1997, 242).

Decisions inherently require the balancing of multiple factors, i.e. goals and criteria, sometimes explicitly, sometimes without conscious thought. In both personal and group decision-making context, the consequences could be substantial and impacting over a long term, influencing many people or generations. The very nature of multiple criteria problems is that there is much information of a complex and conflicting nature, often reflecting different viewpoints that can change over time. It is under these circumstances that tools and methods should be used to synthesise and organise information in a way which leads decision makers to a comfortable and confident decision (Belton and Stewart, 2003, 1-2).

Multiple Criteria Decision Analysis (MCDA) will seldom give the "right answer" or optimal solution as both are concepts that do not exist in a multi-criteria framework, but are products of an optimisation paradigm justified in traditional Operations Research (OR). MCDA is an aid to decision making, a process which according to Belton and Stewart (2003, 3) seeks to:

· Integrate objective measurement with value judgement;

· Identify and manage subjectivity.

Subjectivity is contained in all decision making, from the choice of criteria on which the decision is based, the relative "weight" given to those criteria, to the choosing of goals and objectives (Belton and Stewart, 2003, 3). The aim of MCDA and the principle benefit of it should be to facilitate decision makers' understanding and learning of the problem faced. This deeper appreciation should highlight their own and external parties' priorities, values and objectives in the context of the problem as illustrated in the following quote by Phillps (1990, 150).

> *....decision analysis helps to provide a structure to thinking, a language for expressing concerns of the group and a way of combining different perspectives.*

Note that the focus is on aiding decision making, by providing a structure where all parties can comprehend each others interests, problems and priorities and by doing so try to increase transparency and normalise subjectivity in the decision making process. Normalising subjectivity refers to the concept of not only acknowledging, but adopting the interests of all other parties to minimize variance in subjectivity, theoretically creating benevolent DM, approaching the problem from everyone's perspective. Multi-criteria problems are common and can be identified by the following mutual factors (Hwang and Masud (1979); Hwang and Yoon (1981)):

· Multiple criteria, i.e. goals/objectives and constraints

· Conflicting criteria

· Incomparable units

MCDA involves an in-depth consideration of what exactly the problem consists of, and the creative generation of possible solutions. It is not simply a matter of evaluation of the problem and comparison of alternative courses of action. The process part of MCDA; MCDM consists of two solution techniques (Belton and Stewart, 2003, 13):

· The multi-objective decision making (MODM), which sets to design the best alternative, and

· The multi-attribute decision making (MADM), which selects the best solution among alternatives.

The distinguishing feature of multi-attribute decision making (MADM) techniques is that there are usually a limited number of predetermined alternatives. These alternatives satisfy all objectives, each in a specific way, and the Decision Makers (DM) select the best solution (or solutions) among the alternatives according to priority or weight of each objective.

In multi-objective decision making (MODM) problems the purpose of the model is to find the best alternative, considering none of the solutions satisfy all the objectives. This is done by providing the DM with a design that finds some solution, with acceptable levels for a set of objectives, whilst considering the conflicting interaction between the constraints. The common characteristics of MODM problems are as follows:

· A set of quantifiable and quality objectives

· A set of well defined constraints

· A process of obtaining some trade-off information

· *Efficient Solution:* An ideal solution in MODM problems is one that results in the optimum value of each objective function simultaneously. An efficient solution is one in which no single objective function can be improved without a simultaneous detriment to the other objectives.

· *Preferred Solution:* A preferred (best) solution is an efficient solution, chosen by the DM as the final decision.

Various approaches have been utilised to MODM problems. According to Farahani and Hekmatfar (2009) these can be divided into three categories:

1. Classical: This approach attempts to convert the multi-objective problem into a single objective problem and optimise the new single objective problem. Optimising a single objective problem yields a single solution, consequently the DM has no alternatives to choose from. In addition,

some classical approaches require knowing the optimal solution for each objective, consequently increasing the cost and duration of the problem. The dependency on chosen weights, especially in non-deterministic problems, is another shortcoming of these approaches as the determination of these weights are highly subjective.

2. Pareto Optimal: In this case, a set of solutions are attained when the problem is solved. These approaches utilize algorithms, often evolutionary, to solve multi-objective problems which are more complicated than those that can be solved by deterministic optimization approaches like linear programming. The evolutionary algorithms require less information about the problem to yield a set of solutions.

3. Third Category: There are some approaches which neither convert the multi-objective problem into a single objective or act based on the Pareto Optimal. They are not relevant in this study but their existence bears mentioning.

In the current literature, the most preferred approaches are multi-attribute utility theory (MAUT) and Analytical Hierarchy Process (AHP) (Yang and Lee, 1997, 242). The AHP is a structured method to obtain preference opinion from decision makers. Furthermore, its methodological procedure can easily facilitate multiple objective programming formulations. Developed in the early 1970s, the AHP approach was used to respond to military contingency planning, which combined the utilisation of scarce resources and political participation. This approach involves disintegrating a complex and unstructured problem into a array of multilevel hierarchical components (Yang and Lee, 1997, 242).

In the context of facility location planning these components can be factors that directly influence or differentiate locations, hence called location factors. Both qualitative and quantitative location factors can be considered. The suitability of a specific site depends largely on what location factors are selected and evaluated, as well as their potential impact on organisational objectives. The relative importance of location factors change throughout the decision process. In the initial stages of identifying preferred geographical areas, only priority factors are considered to identify suitable regions. When reaching the stage of selecting specific locations, site specific factors such as costs and access to markets may dominate. In the final stages, some qualitative factors may tip the scales in favour of one location over another (Yang and Lee, 1997, 243).

Location factors can also be addressed in qualitative and quantitative categories. The quantitative type can be measured in numerical values, such as the cost of property and tax incentives. Qualitative types incorporates factors that impact on the ease of operating in a particular area. Such factors cannot readily be expressed in numerical values and evaluated in qualitative models. A popular mechanism of quantifying qualitative input is a method called fuzzy logic which is discussed in Appendix B.

2.6 Location Factors

For proper facility planning, according to Calvo and Marks (1973, 409), an explicit set of social, economic, political and environmental factors should be considered. The suitability of a specific site depends largely on the selection and evaluation of location factors. Unimportant factors, including those which are not site sensitive, should be identified and eliminated from the consideration. Location factors that have been widely used public location research can be adapted to the context of this thesis and grouped into the following main categories (Yang and Lee, 1997, 242): Economic, Environmental, Political, Social and Strategic (Table 2.1).

Table 2.1: Facility location factors.

1	**Economic**
	Access to supplies / resources
	Distance to demand areas
	Economic impact on community
2	**Environmental**
	Climatic operating conditions
	Governmental regulations
3	**Political**
	Co-operation with local industry
	Changing vision of organisation
4	**Social**
	Availability of housing
	Adaptation of families
	Cost of living
	Community attitude / acceptance
5	**Strategic**
	Air freight and rail service
	Fully independent support ability
	Protecting key-point harbours
	Second base

This section attempts to provide a qualitative, inclusive, example of each main category that will have global influence on the location of naval support facilities.

2.6.1 Economic: Trends in Global Military Expenditure

Global military expenditure reached an estimated $1753 billion in 2012, equivalent to 2.4 percent of global Gross Domestic Product (GDP), marking the first real decrease since 1998 (Perlo-Freeman *et al.* (2012, 1) and International Monetary fund (2012)). The small overall reduction is the result of budget sequestration[6] in the USA and spending decreases in most of Western and Central Europe and Australia that were only partly offset by increases in Asia, Eastern Europe, the Middle East, North Africa and Latin America. China, the second largest spender in 2012, increased its expenditure by 7.8 per cent ($11.5 billion). Russia, the third largest spender, increased its expenditure by 16 per cent ($12.3 billion). This point may indicate the beginning of a shift in the balance of global military spending away from the West, although the latter accounts for a clear majority of global military spending (Stålenheim *et al.*, 2005, 177).

In the aftermath of the 2008 global financial crisis, 18 of the 31 countries in the European Union or European North Atlantic Treaty Organization (NATO) have decreased military spending by more than 10 percent in real terms. Even in those parts of the world where spending has increased, the effects of the economic crisis are still evident: decelerating growth in emerging economies has led to slower rates of growth in military spending. In Asia, the average annual rate of military spending has halved, from 7.0 percent per annum between 2003 and 2009, to 3.4 percent per annum in 2009-2012. The effects were more evident in Central and South Asia, where military spending was growing by an average of 8 percent per annum between 2003 and 2009, but by only 0.7 percent a year since, and actually decreased in 2012, by 1.6 per cent. Moreover, the withdrawing of forces in Afghanistan and ongoing efforts to reduce budget deficits in the USA and Europe will likely cause the global total to continue to fall in the coming years (Perlo-Freeman *et al.*, 2012).

The SANDF has, for over two decades, experienced a decrease in military spending as a percentage of GDP. Although the Defence Budget Vote for the 2013/14 financial year amounts to R40,243 billion (US $3.945 billion)[7], this equals to 1,1% of GDP and 3,8% of total government expenditure 2013. As mentioned it is the result of a lengthy decrease, from 4.25% in 1988 to 1.24%

[6]A legal procedure in which automatic spending cuts are triggered.

[7]Using exchange rate of 1 USD = 10.2 ZAR, 30 November 2013.

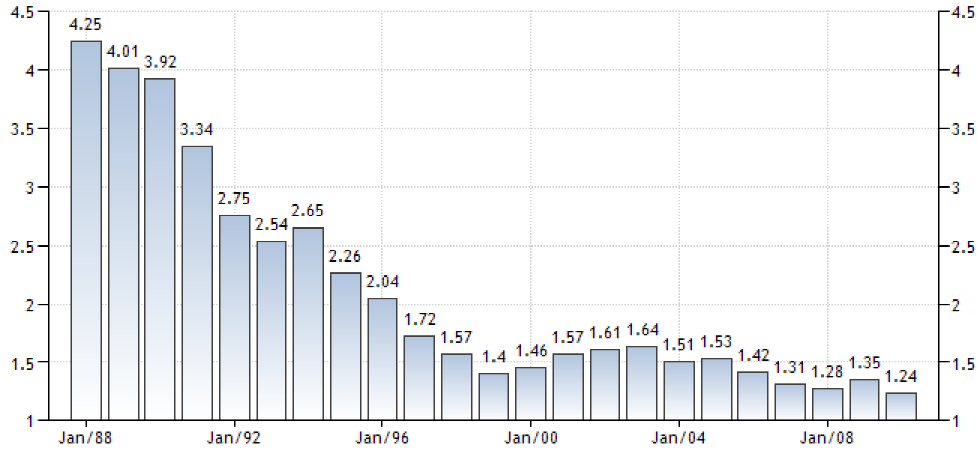


Figure 2.2: Military expenditure (% of GDP) in South Africa, *World Bank*

in 2010 (Figure. 2.2), ultimately ending at 1.1% in 2013 as mentioned above.

Thompson *et al.* (1996) advises that organisations operating in slow-growth/ declining environments, such as the SANDF, have to accept the realities of such an environment and change to objectives coherent with available opportunities, one such objective being a strong focus on cost reduction.

Thompson *et al.* (1996, 180) list some commandments for crafting successful strategies, it will be highly advisable for an organisation like the SANDF to adhere to their implied concepts:

1. *Avoid strategies capable of exceeding only in the most optimistic circumstances.* Read continued operations only in the ELT, thus expect unfavourable operating conditions.

2. *Be cautious of inflexible strategies that leaves little space for manoeuvring.* Inflexible strategies can quickly be made obsolete by changing conditions.

2.6.2 Environmental: Geopolitics and the Northern Sea Route

With the world's maritime transport system at the core of globalization, the emergence of a new sea lane would have global consequences. In anticipation of one such a new sea lane, the Northern Sea Route (NSR), the major trading powers of Europa and Asia are preparing strategies to take full advantage of the opportunity. Current trends in the melting of the sea ice on the Arctic Ocean, piracy and potential political instability along the existing route through the Suez Canal, along with the projected increase in commercial maritime traffic to 2018, all contribute to the promotion of a new regular commercial transit route (Blunden, 2012). The relevance here is the possible decrease in traffic through the Suez Canal and the Strait of Malacca, two bottlenecks in the trade routes between Europe and Asia. The NSR could free up capacity and invite the possibility of lower transit fees through the Canals, leaving the CSR only to service vessels that are too large and destined for ports South of Hong Kong. According to Blunden (2012) the NSR would be shorter for all ports north-east of Hong Kong measured from Rotterdam.

Quoting Blunden (2012) will give the reader an idea of the possible economic advantages offered by the NSR.

> *It was, significantly, a company from Germany, Europe's leading exporter, which in August and September 2009 made the first non-Russian commercial transit voyage, from Ulsan in South Korea to Rotterdam. Beluga Shipping's use of this route, normally open for only a short time each summer, shaved 3,000 nautical miles off the Suez Canal route, making estimated savings of $300,000 for each of the two vessels involved. In September 2011 the Polarcus Company's seismic vessel Polarcus Alima completed the transit of the route from Hammerfest in Norway to the Bering Strait in nine days, en route for New Zealand, giving a glimpse of the potential global possibilities. The expected saving in the full voyage from Norway to New Zealand, compared with the Suez Canal route, is 13 days.*
>
> *Enthusiasts for the Route were encouraged in late summer 2011 by the successful transit of the Japanese-owned Sanko Odyssey, the world's largest ice-class bulk carrier, from Murmansk to China in 23 days, approximately 22 days less than the Suez Canal route.*
>
> *German policy-makers are aware that a potential shorter maritime trading route through the Arctic would bring Germany high profits, estimated, for large vessels, at up to half a million euros per trip.*

There is also the possibility that major political conflict arises in the Arctic region, see Figure 2.3, as most interested parties have not challenged Russia's *de facto*[8] control of the region, propped up by its regional military superiority, regulatory regime and 17,500 kilometre Arctic coastline. To emphasise the tension regarding Arctic matters, in October 2010 Senior Admiral Vladimir Vyotsky warned that Russia, "would not give up a single inch in the Arctic." As evidence, the Russian name, the Northern Sea Route (NSR), is increasingly

[8]in fact, whether by right or not.

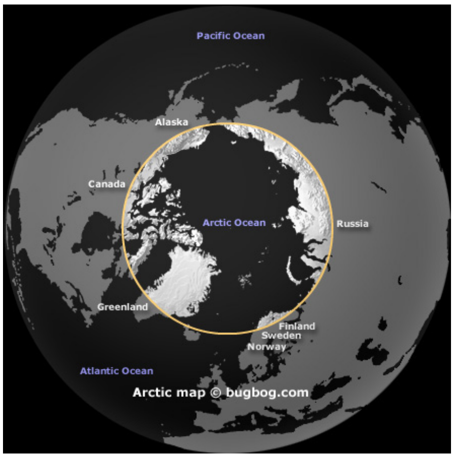


Figure 2.3: Delineation of the Arctic Ocean.

being used rather than the European term, the North-East Passage (Blunden, 2012).

Piracy in the South China Sea has intensified but could escalate further as traffic increases but there is a general consensus that the development of a new main sea highway linking Asia and Europe would greatly enhance the security in that area. Blunden (2012) concludes by stating that "something beyond the scope of piracy- such as political interference, the outbreak of war, or violent civil unrest in the volatile regions bordering the existing route could shift existing global trade patterns and accelerate the technological and other innovations necessary for mass commercial utilization of the NSR."

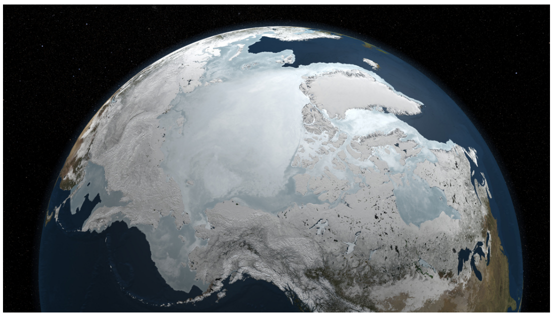


Figure 2.4: Satellite image of Arctic ice cover. PHOTO: NASA.

The conception and possible realization of the NSR will have a dramatic impact on the CSR and the operating environment of the SAN, albeit positive or negative, and could be a definitive factor in any future strategic design.

2.6.3 Political: The Role of Private Military Companies

Most people would agree that society's global and definitive objective, in economic terms the ultimate benefit sought, is peace and security. Consequently, if that is the demand, it will be provided either by public or private organisations, even if the result is imperfect (Brauer, 2008, 111).

Mercenaries, or contractors as they preferred to be called, provide a solution to large commitments of political and economic resources to provide security and stability or to fight wars. Whether on land or sea, contractors are a source of impermanent forces capable of providing specialist capabilities, whilst providing deniable accountability in the political domain. Military manpower has often been viewed and treated as a commodity, with providers bearing the cost of maintenance, recruiting and equipping, while the customer pays cash. This agreement takes place within the constraints imposed by domestic political and economic realities. In the past, such arrangements were propagated because it limited the impact on the economy of the sovereign and permitted greater leeway by not engaging the population. (Armstrong, 2007, 161-162)

The history of organising warfare shows cyclical movement, sometimes more private, sometimes more public, always a mixture. What changes are the conditions under which principle is better suited to the purpose of fighting wars of keeping the peace (Brauer, 2008, 111) . Today the role and impact of the Private Military Company (PMC), and more specifically the Private Security Company (PSC), have changed as the rules of war have changed. Understanding how they impact strategic, operational, and tactical operations is essential (Armstrong, 2007, 161).

Mercenaries were regular features in war, from their first recorded use four millennia ago, up until the nineteenth century. It would be two hundred years after the birth of the modern state[9] before states would effectively hold each other accountable for the actions of their citizens, consolidating the decision to personally volunteer to fight in wars away from the populace and into the hands of the governments of states. It was not policy or treaties that disarmed mercenaries, but a confluence of nationalism, technology, and increasing interstate trade that marginalised them (Armstrong, 2007, 162-166).

This convergence sprang from the implementation of universal conscription in France, six years before Napoleon took control. The result was a revolution-

[9]The *Peace of Westphalia* was a series of peace treaties signed between May and October 1648 in Osnabrück and Münster. These treaties ended the Thirty Years' War (1618-1648) in the Holy Roman Empire, and the Eighty Years' War (1568-1648) between Spain and the Dutch Republic, with Spain formally recognizing the independence of the Dutch Republic.

ary source of manpower to fight wars, mobilising people through nationalism and patriotism on an unprecedented scale. It was not just the sheer size of national armies that decreased the use of mercenaries, but also the amount of state control over these forces, supported by the increased professionalism of the officer corps. Nationalism, new weapons technology, tactics, and strengthened command and control meant the common soldier could now be the citizen-soldier with little military experience (Armstrong, 2007, 166).

Evident from the history of mercenaries, especially over the period of their disarmament two hundred years ago to their resurgence today, is an inverse relationship between demand and state autonomy. Globalisation has caused previously ossified geographical and functional borders to become more permeable or disappear altogether. As a consequence, new options are available to states, as well as new restrictions. Global trade and communication force states to restructure their goals to address a broader audience. In this new environment, modern leaders find themselves with similar capital shortfalls as their pre-Westphalian predecessors, mostly in the area of political capital that extends beyond their border (Armstrong, 2007, 185).

Figure 2.5: Different roles of a Private Military Company (PMC).

There are different ways to categorize PMCs. Armstrong (2007, 163) places the function and purpose of a PMC along a horizontal axis of a spear as illustrated in Figure 2.5. At the tip are "military provider firms" with implementation and command capabilities, denoting the lethal side of PMCs. "Military consultant firms" are found in the middle, which provide advisory and training services. The third and last category is "military support firms," which provide non-lethal aid and assistance like food services, transportation, and latrines.

Considering all of the above, the question then is, could a PSC not provide military support to the anti-piracy operations of the SAN? This non-lethal aid could be in the form of providing vessels, and the operation thereof, to "charter" police or marine protection officials to positions from where they can launch boarding parties to inspect suspect vessels. An added advantage could be that officials from multiple nationalities can be accommodated on a single vessel,possibly allowing jurisdiction over neighbouring territories.

2.6.4 Social: Adaptation of Military Families

Military communities are usually embedded in larger civilian communities that face many of the same challenges. Not surprisingly, an investigation focussed on the U.S. Air Force found that the implications of a military community study apply to civilian communities as well. The ability of military families to adjust to or bear the demands of a military lifestyle is influenced by the interaction between the formal and informal network components of the overall social organisation. Formal networks reflect the military policies and systems as instruments of socialisation, support and social control. Informal networks reflect personal and collective relationships or associations in a voluntary and less hierarchical environment (Bowen *et al.*, 2003, 33).

Bowen *et al.* (2003) propose a model to explain the variation in family adaptation by combining the influences of formal unit and informal community support, sense of community, as well as the presence or absence of children in the residence (Figure 2.6). Unit and informal community support are proposed to affect family adaptation indirectly through their direct effects on sense of community. Unit support is also expected to have another indirect influence on family adaptation through its direct effect on informal community support. Base and housing location as well as tenure in the community have indirect influence on family adaptation through their direct effects on sense of community.

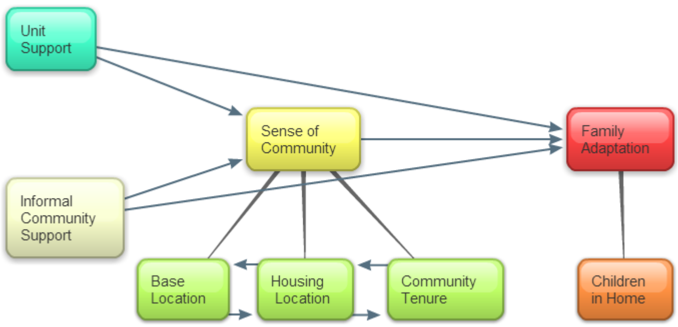


Figure 2.6: A family adaptation model adopted from Bowen *et al.* (2003, 34).

The direct and indirect relationships between family adaptation, unit and informal community support and sense of community proposed by Bowen *et al.* are hypothesised as positive. Unit support and informal community support are the cornerstone elements of social organisation in the military community. For example, unit leaders play a critical role in encouraging and promoting informal initiatives to support the linkages between members and among military families. The suggested linkages are supported by social capital literature and disorganisation theory (Bowen *et al.*, 2003, 34).

The different concepts are defined by Bowen *et al.* (2003, 34-36) as follows:

· *Unit Support*: The military unit represents the primary organising feature of any armed forces. For most members it represents the group of subordinates, peers and superiors with whom members interact on a daily basis. The concept of unit support is defined as the extent to which military members and their families are able to secure informational and social-emotional support from unit leaders. Consequently, unit leaders have a fundamental responsibility for sustaining and promoting the well-being of unit members and their families, a responsibility greatly exceeding the responsibilities of their civilian counterparts. Unit leadership can support the larger military community by encouraging unit families to become involved in formal and informal civic activities. Research suggests that the direct influence of unit support, when quantitatively measured, has small to modest effects on family adaptation, therefore suggesting that influence may be more indirect than direct.

· *Informal Community Support*: Informal community networks are those interactions, associations, exchanges and connections that people and families make daily. Interaction within the informal network may be intense or remote, constant or permitted, or it may be goal orientated or even without purpose. Informal networks and the inherent support they provide influence how positively people experience their neighbourhood (sense of community). In a study of 180 married U.S. Air Force members, they reported a strong and significantly positive relationship between community connections and sense of community. This network can serve as a resource in solving various family problems connected with military life in particular. Social support generally, and community support in particular, act as buffers for strain associated with military family adaptation.

· *Sense of Community*: Sense of community is defined, in the military context, as a psychological variable reflecting the degree to which members feel positively attached to the military as an organisation. Identification within the military community and attachment to such a community, rather than the broader civilian community, reflects the interest of members to develop their own sense of community.

· *Base location and tenure length*: The location of the base, housing (off or on base), and length of time members have been assigned to the base community were included in the family adaptation model. In an earlier paper, Bowen *et al.* suggested that sense of community might be higher among members who lived on the base and among those who have served on the base for a longer period. By allowing these three variables to influence sense of community, the model provides for their potential effects. In one of his earlier articles published in 1998, *Effects of leader support in the work unit on the relationship between work spillover and family adaptation*, Bowen reported that the presence of children in U.S. Army homes was associated with lower internal family adaptation for both male and female soldiers. It is taken as conclusive evidence that military couples with children experience greater work-family conflict than those without children in the home, thus children have a direct influence on family adaptation. The model built by Bowen *et al.* (2003) provides for such influence.

Bowen *et al.* found that overall results from their analysis supported the model whilst revealing several important insights relating to the pathways between the components of the model. The direct effects of formal and informal networks were modest, however the findings suggest a more complex and meaningful method of how unit and community support influence families. The significance of sense of community emerged as an important facilitator between unit and community support networks and family adaptation. As expected, people living on base reported a greater sense of community. A substantial connotation was established between number of children in the family and family adaptation, resulting from families with children in the home reporting lower adaptation levels, thus suggesting that more complex family structures place greater demands on the family system (Bowen *et al.*, 2003, 41).

Most armed services have a long history of providing support to its members on various levels. Such support could, through policies and practices include, allowing soldiers time off for family emergencies or activities, provide means for deployed soldiers to communicate with their families, provide relocation assistance when soldiers are deployed and support spouses in employment endeavours (Bourg and Segal, 1999). Thus Bowen *et al.* (2003) suggest that increasing unit support will act as a pivotal leverage point in working from a community-based prevention focus. To conclude this section, it was found that unit support has a substantial influence on sense of community, which in turn significantly affects family adaptation. It is therefore crucial that unit leaders, and the unit as a whole, take the state of their community and the accompanying responsibilities seriously.

2.6.5 Strategy: The Scramble for Africa

The heavy dependence on seaborne trade, coupled with the small number of deep-water ports available, presents a real strategic opportunity for an outside entity to cause considerable economic harm to any African state. It is not very difficult to close a port by laying mines or sinking a ship in the entrance. The United States demonstrated this in Nicaragua[10]and Iraq and Iran in the mining of the Arabian Gulf [11]. The economic importance of Africa's maritime domain therefore extends into the strategic arena.

Naval forces are usually seen as "the first line of defence", even in the non-traditional role of mitigating the effects of disasters, be it the case a surge of flooding or accidents at sea (R Adm Yotamo, 2009). At a military strategic level the primary importance of the maritime domain lies in the assumption that any serious military threat must come by the sea: an overland deployment of large forces is not practical in Africa, and air transport is complex and costly (Heitman, 2009, 46).

This is of particular importance in an era in which major powers are escalating their presence and influence in Africa as a means of securing access to essential raw materials, emerging markets and building a network of client states (Barth, 2003, 679). Africa is the only large part of the world that is both accessible to such powers and vulnerable to the full spectrum of outside influence. It is not news to hear of foreign military advisers, equipment and proxy forces being deployed to protect foreign interests in African countries (Heitman, 2009, 46).

A strategic analysis of the naval and maritime assets available to Sub-Saharan Africa suggests that permanent multi-national naval forces should be developed with smaller countries providing standby assets. These permanent forces should be funded by the economic regions (SADC and ECOWAS[12]) whilst those littoral states capable, provide the assets and the operation thereof. Smaller countries can commit certain maritime assets to form part of an standby force whilst capable countries commit specialised vessels to such an force. An effective use of such an standby component would require great co-operation between African navies, possibly leading to a single operations room that will deploy the best-placed vessel or aircraft to any incident (Heitman,

[10]In 1984 the International Court of Justice (ICJ) ruled in favor of Nicaragua and against the United States and awarded reparations to Nicaragua. The ICJ held that the U.S. had violated international law by mining Nicaragua's harbours. The U.S. later blocked enforcement of the judgement by the United Nations Security Council and thereby prevented Nicaragua from obtaining any actual compensation (International Court of Justice, 1986, 14).

[11]On 18 February 1991, the USS Tripoli (LPH-10) struck an Iraqi contact mine; four hours later, the Aegis cruiser Princeton (CG-59) fell victim to a Manta mine. It took the multinational Coalition Forces more than two years of intensive mine-countermeasure (MCM) operations to declare the northern gulf mine free (Khan, 2010).

[12]Economic Community Of West African States (ECOWAS), consisting of 15 West African countries of which Nigeria is the major economic power.

2009, 51).

A realistic approach would suggest that there should be two such forces, one in Nigeria and the other in South Africa. These countries currently have the largest and most balanced fleets and would be able to provide the core force and specialised assets. Political realities may call for another force in the east Africa region, which will again draw from the South African Navy for its core force. It is therefore imperative that Africa should seek to formally involve France, which is technically a neighbour[13], in such a regional force. Therefore the SAN needs to be seen, externally and internally, as a component of regional maritime security in addition to its primary role (Heitman, 2009, 52).

2.7 Chapter Summary

The literature review addresses two of the three fields of study, namely facility location and strategic management, that are at the centre of the research domain and form the foundation of any serious solution attempt. Chapter 2 therefore aims to contextualise the problem within literature.

The two opening sections of the literature convey the fundamental understanding of facility location and the uncertain nature of the time component. Therefore, the first section investigates the origin of facility location, with the aim of classifying the problem within literature. Starting with the static and deterministic model, the following three classes of models were identified; median problems (of which the most popular is called the P-median), covering problems and center-problems. The P-median problem, or otherwise known as a *location-allocation problem*, strives to simultaneously locate facilities where they will best interact with other facilities and demand nodes. Consequently, literature that builds on P-median theory was researched which lead to hierarchical (multi-level) location-allocation models. Since the problem has a multi-level maintenance component, it is therefore identified as a hierarchical location-allocation problem.

On the basis thereof, the second section originated from the continuous mentioning of uncertainty concerning "real-world" problems. This lead research to the field of *stochastic and dynamic optimisation problems*. Dynamic models attempt to place facilities in optimal or near-optimal locations over a specified time horizon by assuming input variables are initially known and change deterministically with time. The stochastic literature is divided into two classes according to Owen and Daskin (1998, 435): that which explicitly considers the probability distribution of uncertain parameters, and that which

[13] *Mayotte* and the *Scattered Islands* in the Indian Ocean are French territories in the Mozambican Channel, each with its own EEZ.

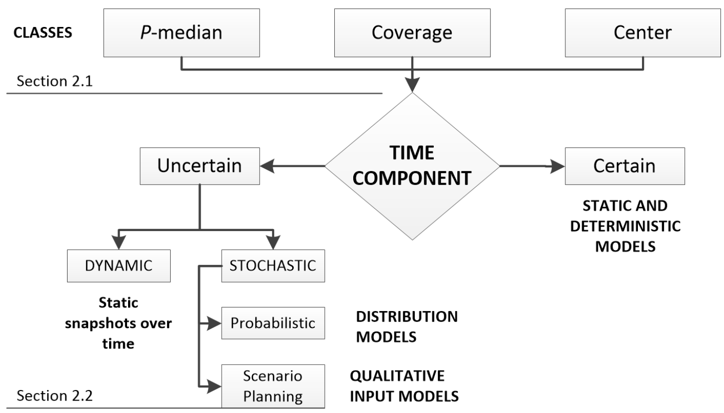


Figure 2.7: Facility location review.

captures uncertainty through scenario planning, consequently, requiring that any reasonable model consider some aspects of future uncertainty. In both cases, any number of system parameters might be taken as uncertain and even relatively certain parameters might be presented as a probability, such as construction costs or travel times. Figure 2.7 can be consulted for a graphical overview of the research process.

The scope of this thesis does not permit the additional complexity and the timely collection of data that accompanies probabilistic models, hence such inputs have purposefully been circumvented. Consequently, more focus was given toward the scenario planning approach, which was developed by Marianov and Serra (2002) to minimise distance across multiple scenarios using the P-median formulation as a basis. Their model has been successfully used to find optimal locations for fire stations in Barcelona, considering different travel time scenarios.

The second of the two main concepts, strategic management is investigated in Section 2.3. It conveys the basics of strategic management focussing on management in the public sector. The propositions presented in this section reflect some of the unique aspects of strategic management in public organisations but may also apply to strategic management in the private sector in some context. To conclude, authors Ring, Perry, Poister and Streib agree that there are fundamental differences between strategic management in the public sector and in the private sector. These differences lead both articles to propose conforming guidelines to improve such management strategies in the public sector. Ring and Perry propose that leaders in the public sector should develop outward looking, short-term strategies by preparing for the most probable external influences.

The fourth section explores the domain of scenario crafting, using a technique developed by Chantell Illbury and Clem Sunter which presents different scenarios in a matrix rather than listing them individually. Section 2.4 provides a basic understanding of their method through the use of an example. The second last section briefly investigates decision making models, of which the most popular is the Analytical Hierarchy Process (AHP), to provide a decision making mechanism in which to evaluate the results of the optimisation model.

The final section, Section 2.6, compliments the location planning process by grouping additional location factors into the following main categories (Yang and Lee, 1997, 242): Economic, Environmental, Political, Social and Strategic. It then provides an example factor for each category in detail.

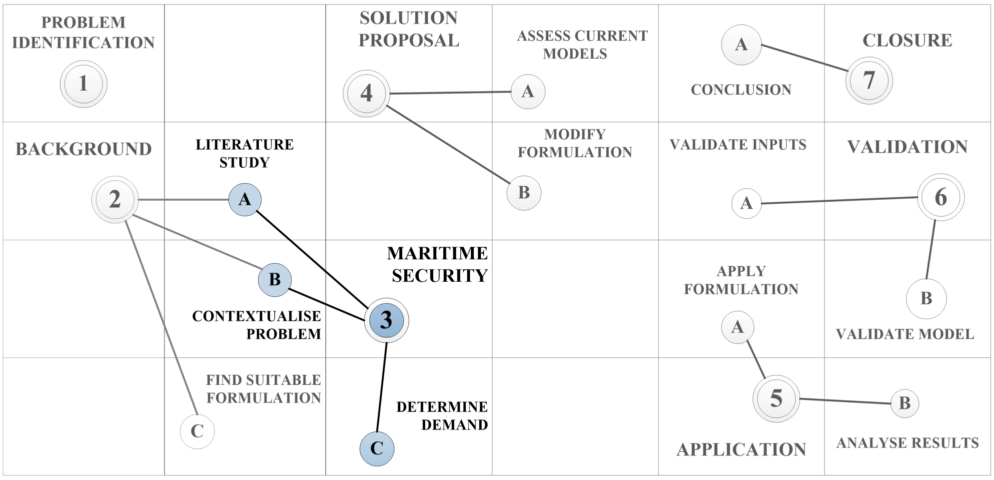
In summary, Chapter 2 provides the majority of the literature study for this thesis in the OR domain. It identifies the theoretical models applicable to the problem, namely the hierarchical P-median and scenario planning models.

Chapter 3

Environment of the South African Navy

Chapter Aim:

This chapter aims to introduce the physical environment of the South African Navy (SAN), as well as the concept of maritime security. Within this context, the economic importance of Africa's maritime domain is explained as well as the difficulties faced in stabilising affected regions.



Chapter Outcomes:

- Supplement contextualisation of problem.
- Definition of maritime security.
- Provide economic reference.
- Identification of present and future demand regions.

3.1 Why does South Africa need a Navy?

This is probably the most asked question by civilians. Whoever they may be, people aren't sure why South Africa really needs a Navy. This section was inspired by a blog written by Horatio Drake, a Combat Officer in the SAN. Section 3.1.1 is a direct extract from his blog as he answered the question posed by the section heading.

3.1.1 War is a reality

> *The first argument people put forward often goes like this: "But why do we need a Navy? It's not like we're ever going to make war against anyone."*
>
> *A fair comment if you look at the current situation in South Africa. But what did people call World War 1 again? The War to end all wars. In 1918 it was inconceivable that the world would ever again see a conflict of that magnitude. Twenty-one short years later, Germany invaded Poland.*
>
> *To think that just because South Africa is currently enjoying a precarious peace, we will never see conflict in our lifetimes is just plain naive. In fact, if the young amongst us live their whole lives without seeing another war, they would most probably be the first generation of Southern African inhabitants to do so!*
>
> *In the event of a war or conflict in the African Battle Space, a professional navy will be a massive boon to South Africa. As one of very few countries in Africa with a functional navy, the control of the sea will give South Africa a distinct advantage in any conflict.*
>
> *Unlike an army, a navy cannot be recruited and trained in a short time. Not only is the acquisition of platforms a long process, but the technological nature of modern warships means that the average sailor almost needs an engineering degree to operate the onboard systems!* - Horatio Drake.

3.1.2 Warships as instruments of Diplomacy

The contributions of warships to the diplomatic sphere is clearly based on their ability to project power and to exercise military force. Naval forces have the unique ability to maintain a non-hostile image, unlike the deployment of land- and air forces. In the post-Cold War environment, navies more frequently conduct operational duties or "maritime operations other than war" such as low-level policing, diplomacy and coercion than traditional high level operations (Potgieter, 2009, 15). It therefore requires that navies are used to their fullest extent as diplomatic instruments by evolving and exploring the boundaries of their new roles. Ken Booth contributes the following insights from his book *Navies and Foreign Policy.*

> *"A State with a Navy is potentially a neighbour to any state with a coast"* - Booth (1977, 33)

An advantage of warships as instruments of political escalation is the greater ease with which force can be increased, as there is an absence of resident populations at sea as a complicating factor and the non- territoriality of the seas (Schäfer, 1998). "Like tank warfare in the desert, naval diplomacy has a clarity and an absence of the collateral complications which are usually present with the use of other instruments of the diplomacy of violence" was the example given by Booth (1977, 33). Booth further elaborated on the non-territoriality of the seas by saying "the fact that warships operate at sea will often enable them to withdraw from ostensible commitments with more speed, fewer costs and less loss of face than would be entailed by deployed ground forces, or aircraft and the accompanying logistic tail."

3.2 The Southern Oceans

South Africa lies along a major international sea trade route, or Sea Lane of Communication (SLOC), and is located far from its key trade partners classifying it as an economic island. Over 95 percent of South Africa's trade by volume is dependent on sustaining these SLOC's. Therefore the security of South Africa's maritime trade routes are a fundamental matter of national security, allowing trade and economic growth. South Africa has a measured coastline of 3824 kilometre and an EEZ of 1 537 000 km^2 of which 474 400 km^2 comprises of the areas around Marion and Prince Edward Islands[1] illustrated in Figure 3.1(R Adm Bennet and R Adm (JG) Söderland, 2008, 1-6).

The 3824 kilometre coastline host both the Atlantic and Indian Oceans, exposing South Africa to the strong Mozambique current down the east coast and the light Benguela up the west coast. Along the southern tip of the continent, the shore descends gradually to a depth of 200 metres until it suddenly descends, forming an undersea cliff face, to depths greater than 2 500 metres. The significance is that this undersea cliff is close to the coast, varying between less than 10 kilometres along the east coast and out to 100 kilometres at

[1]In December 1947 and January 1948 the HMSAS *Transvaal* took possession of both Marion and Prince Edward islands respectively under the command of Lieutenant-Commander John Fairburn. These islands are located some 955 nmi (1,769 km) south-east of Port Elizabeth in mainland South Africa

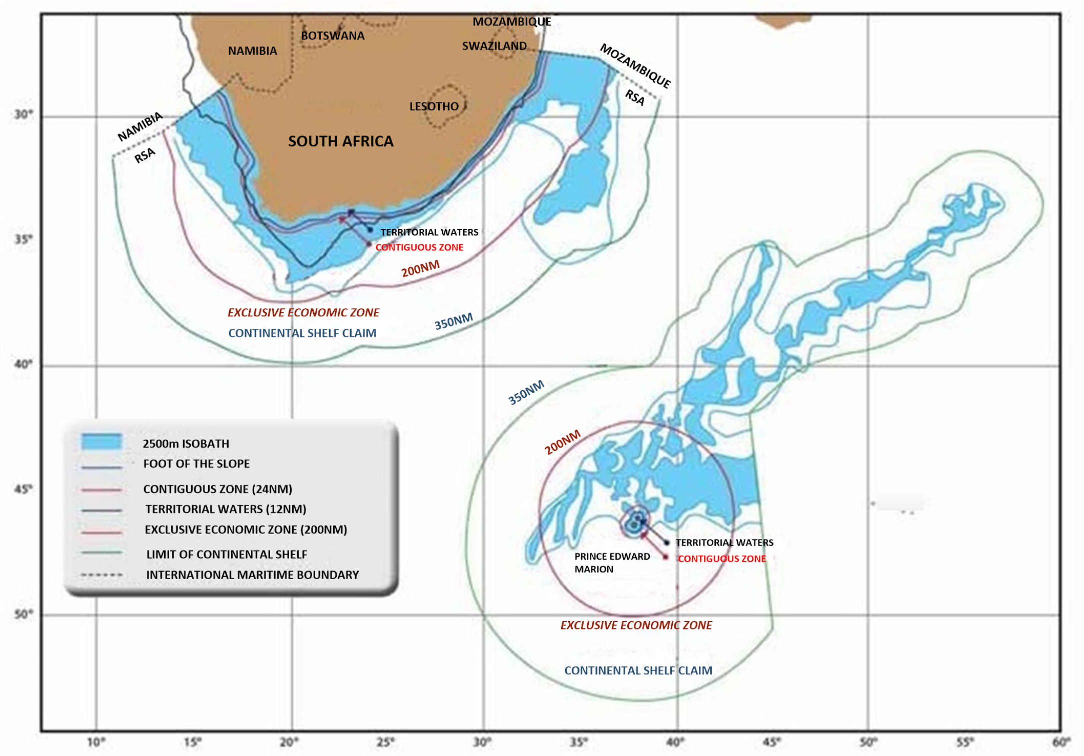


Figure 3.1: South Africa's Economic Exclusive Zone (EEZ).

Cape Agulhas. The natural result is that the Mozambique current attains its strongest flow, of up to 5 knots (9 km/h), close to this undersea cliff (Honiball, 1996, 2).

To maximise efficiency, ships passing around the South African coast aim to take maximum advantage of the south westerly flow of the Mozambique current. Consequently, they tend to navigate where the current is strongest, rounding the Cape of Good Hope and Cape Agulhas as close as is permitted by regulations, in order to keep the voyage as short as possible. Ships that have to proceed against the current when going from west to east around the South African coast, are able to avoid the strong current by sailing close to the coast, less than 8 km where there is a counter-current. The result is that more than ninety per cent of the shipping around South Africa is close to the coast, seldom further than 50 nautical miles (90 kilometres) away (Honiball, 1996, 2).

The economic importance of the maritime sovereignty originates from two factors. The first being the natural resources to be found in the area, while the second relates to its use as a means of transport (R Adm Bennet and R Adm (JG) Söderland, 2008, 1-6). According to Du Plessis (1987, 19) South Africa's most important fishing area is the Southeast Atlantic area, stretching from Angola past Cape Agulhas, which supports an industry consisting of "pelagic fishery, demersal fishery, handline fishery, rock lobster fishery, marine mammal fishery and the collection of guano." Energy resources refer to the common practise of extracting oil and gas as well as exploiting renewable energy sources such as tidal and wave power.

As a means of transport, roughly 30 percent of the Middle East oil destined for Europe and the Americas conveys via the Cape Sea Route (CSR). It is in fact the only alternative to the Suez Canal for the growing number of Very Large Crude Carriers (VLCC) and Ultra Large Crude Carriers (ULCC), thereby increasing the importance of the CSR (Du Plessis, 1987, 24-25). In times of conflict, especially in the notoriously unstable Gulf of Aden, the Cape sea route will be the only efficient alternative, as demonstrated by the Six-Day Arab-Israeli War which led to the closure of the Suez Canal from 1967 to 1975 (Wessels, 2010, 115).Therefore, these waters need to be patrolled and surveyed to ensure South Africa's maritime security as well as to fulfil international hydrographical and maritime search and rescue obligations.

3.3 Maritime Security

Maritime Security is a somewhat broad and unstructured concept, thus it is virtually impossible to comprehensively focus on all its elements without the danger of giving one or more of the elements a greater sense of importance. This section will therefore not attempt to define maritime security but give some account of this wide-ranging topic to the reader.

In literature on maritime security the focus can be varied, ranging from physical security measures, shipboard security, registration of ships, piracy, phantom ships, maritime safety issues, illegal immigrants and stowaways. Therefore the definitions, interpretations and level of importance depend on the originator and the topic under discussion (Potgieter, 2009, 6).

Germany regards its maritime relations as crucial for economic prosperity as they are dependent on the import of raw materials and the export of manufactured goods. As a result the German Navy has developed expeditionary capabilities to provide maritime security, physical or otherwise, wherever in the world it necessitates to protect German interests. Thus their security focus is centred around regional surveillance, protection of SLOC's and defence against asymmetrical threats. Global maritime security and sea power are critical concepts to the United States regarding US security and prosperity. Consequently, the US strategy focusses on mitigating the threats of piracy, terrorism, weapons proliferation and drug trafficking, therefore providing a networking platform for the US Navy, Coast Guard, the Marine Corps, as well as international partners, to secure maritime links and security at sea (Potgieter, 2009, 6).

The interests of nations, in maritime security terms, are therefore focussed around the following objectives according to Potgieter (2009): to facilitate maritime commerce and economic activities at sea; and to protect the maritime domain against ocean related threats such as piracy, pollution, terrorism, poaching and other criminal activities. This ideal state can best be achieved by merging naval and private maritime security activities in an international cooperative sphere, since those involved in illegal activities at sea usually do not care for national or international boundaries (Potgieter, 2009, 7).

The responsibility of maintaining maritime security around the coast of Africa has shifted from colonial trading powers to Africa itself. But African navies are small, and even participating for a finite time in multi-national naval task force would be a challenge, not to mention their abilities to maintain maritime sovereignty in their own waters. Therefore, in the Southern African context, maritime security consists of border patrol, policing,anti-poaching and anti-piracy operations.

3.4 Economic Importance of the African Maritime Domain

The majority of Africa's exports (raw materials, agricultural produce, oil) and imports (manufactured goods, oil and fuels) travel by sea, as there is no real alternative. Africa's seaborne trade will have to expand in capacity and opportunities if Africa's economies are to grow. It is also likely that coastal shipping will develop as African countries increase trade with each other, seeing that the overland transport infrastructure is inadequate. It is important to bear in mind that Africa's landlocked countries depend on seaborne trade for their major imports and exports (Heitman, 2009, 44).

3.4.1 Offshore Oil and Gas

Oil and gas are important elements in the broad African economy, with a high proportion of oil and gas reserves found offshore, on islands or in coastal areas. These reserves are not enormous, but offer significant quality advantages. Being lighter, oil from the Gulf of Guinea is easier and more economic to refine that Middle Eastern crude. Additionally, the continent's strategic location offers decent sea-lanes to the West and East. The exploration of significant resources on new offshore locations offer a potentially stable security environment, on account of their distance from the mainland. The volatility of landward and coastal oil-producing facilities is well documented. Given the volumes of African oil being lost, estimated at 200 000 barrels per day (some 10% of daily production (Gambrell, 2013)) in Nigeria alone, due to unrest and conflict. Deep offshore locations may offer a way around land-based vulnerabilities and represent a major step towards securing oil flows. (Vrey, 2009, 90).

These recent figures (Table 3.1) illustrate the importance of oil production in the Gulf of Guinea (Heitman, 2009, 44):

Table 3.1: Oil production in the Gulf of Guinea.

Nigeria:	Oil accounts for 95% of exports and 14% of GDP, the majority from the Niger delta and offshore fields.
Angola:	Oil accounts for 92% of exports and 47% of GDP, again the majority from offshore fields.
Equatorial Guinea:	Oil accounts for 90% of exports and 60% of GDP, almost completely from offshore fields and islands.
Gabon:	Oil accounts for 80% of exports and 40% of GDP, much of it from offshore fields.
Congo:	Oil accounts for 95% of exports and 67% of GDP, the majority from offshore fields.

Africa's economic development will thus depend on the stabilisation and efficient exploitation of its maritime domain. The ensuing economic activities will, sooner or later, attract criminals, rebels, terrorists or foreign forces to such areas of operations. A potential arc of conflict stretches from Sierra Leone in the west past the Ivory Coast, Nigeria and down to the Republic of Congo, DRC to Angola in the south. The volatility currently found inland will directly affect the adjacent maritime domain as it is not possible to have maritime security amidst such continental insecurity (Vrey, 2009, 92).

A current example is how the Movement for the Emancipation of the Niger Delta (MEND) has developed its strategy: They started off with "bunkering", a method of siphoning oil from pipelines, to raise cash. They quickly capitalised on the strategic vulnerability and moved on to attacking oil installations and taking foreign employees hostage. Soon afterwards MEND escalated their operations by capturing and briefly occupying offshore platforms close to the coast. These activities reached unprecedented levels in 2008 when they attacked Nigeria's first and largest offshore field, taking and briefly holding the Bonga production, storage and offloading vessel, 120 km offshore. It can be assumed that groups like the MEND's striking capabilities are continuously improving as they remain unchecked in Nigeria's maritime domain (Heitman, 2009, 55).

There is a potential threat, in that these successes can inspire and educate similar guerilla activities in other states. One could see such developments around Equatorial Guinea's Malabo Island, which lies off Cameroon. There is also the question of how long before the Islamists in Somalia develop a political dimension in the Somali pirate industry.

3.4.2 Offshore Mining

Offshore diamond mining is an important contributor to the South African and Namibian economies. The potential mining of other mineral resources remain to be explored as they are found in a wide variety on the ocean floor, mainly falling into four categories:

Table 3.2: Mineral resources found in the Ocean.

Granular sediments:	quartz-rich sand and gravel, shell, silt and clay.
Hydrothermal minerals:	products of volcanic activity and results in sulphide deposits rich in copper, zinc, lead and gold.
Placer Minerals:	gold, diamonds, tin, platinum and titanium.
Hydro-genetic:	phosphorite, salt, barite and other rare minerals form when seawater precipitates under various conditions.

Other than the minerals mentioned in Table 3.2, the ocean provides resources in the form of an oxygen producer and climate buffer (Marine Bio Conservation Society, 2013).

3.4.3 Fishing

Fishing, in its commercial or subsistence form, are important sources of foreign earnings in littoral countries and food for much of Africa. Heitman (2009) gives some recent figures (Table 3.3):

Table 3.3: African fishing industries.

Namibia:	The fishing industry generates some 10% of GDP
Ghana:	The fishing industry generates some 7% of GDP and 60% of the nations animal protein intake, directly supporting 14% of the population.
Senegal:	The fishing industry generates some 7% of GDP, 33% of exports and 75% of the nations animal protein intake.
Angola:	The fishing industry produces 50% of the nation's animal protein intake
Guinea-Bissau:	The fishing industry generates 50% of the government revenue.

Fish, abalone and kelp are in their infancy in Africa, but have considerable potential.

3.5 The African Delinquency

Most African countries have "an agricultural mentality" according to a former Chief of the South African Navy, in the sense that they do not pay sufficient attention to their respective maritime domains. There may be historical, geographical and economical reasons for this, but to neglect the maritime domain is politically, economically and strategically dangerous (Heitman, 2009, 43):

· It cedes control over a large part of national territory.

· It leaves economic activities and resources unprotected.

· It neglects to monitor the primary approach route of any serious enemy.

There can be no doubt that securing the maritime domain influences economic development and peacekeeping efforts. The crucial problem is that few African states have any relevant naval capability. A simple comparison will be drawn between the territory and force composition of Sub-Saharan Africa and that of Germany. Table 3.4 provides a comparison of the territorial responsibilities of the two entities.

In the case of Sub-Saharan Africa, and adding to the previous paragraph, it is a large territory to ignore or leave unprotected. To patrol their respective territories, the comparing nations have the following vessels at their disposal,

Table 3.4: Territory comparison between Sub-Saharan Africa and Germany.

Criteria	Sub-Saharan Africa	Germany	Unit
Coastline	21 000	2 400	km
EEZ	7 800 000	57 500	km^2

as seen in Table 3.5.

Table 3.5: Force comparison between Sub-Saharan Africa and Germany.

Criteria	Sub-Saharan Africa	Germany
Ships in total	145	84
Frigates or larger ships	5	13
Total maritime aircraft	25	53
Medium-range patrol aircraft	7	8

Note that not all these platforms are fully operational nor can they all be deployed at the same time, due to maintenance schedules or other commitments. The combined forces of Sub-Saharan Africa clearly do not enjoy an adequate force to area ratio. The primary point is that most African countries are simply too poor to develop or support the necessary maritime forces. Some basic numbers from 2012 add to this point (International Monetary fund, 2012):

· The whole of Africa had a GDP of some $2,016 billion, roughly two thirds of Germany's GDP or the same as Italy's or Russia's.

· Sub-Saharan Africa had a GDP of some $1,300 billion, roughly the same as Spain.

· Sub-Saharan Africa without South Africa had a GDP of some $930 billion, roughly the same as Indonesia.

· Sub-Saharan Africa without South Africa and Nigeria had a GDP of some $660 billion, roughly the same as Saudi Arabia or slightly more than Switzerland.

· Only two countries in Sub-Saharan Africa, namely Nigeria and Angola, had GDP's larger than that of Johannesburg.

· Only three countries in Sub-Saharan Africa, namely Nigeria, Angola and Sudan, had GDP's larger than that of Cape Town, and the latter only barely

It is worth noting that the financial situation of Sub-Saharan Africa is much worse. The per capita income in most African countries is very low and economic development is hindered by infrastructure backlogs. Consequently, there is no real prospect of African countries developing effective naval forces in the near or medium-term future. This does not mean naval spending is unjustified as any meaningful objectives will be out of reach. It simply means that African countries must make optimal use of their combined naval and maritime assets (Heitman, 2009, 50).

The German and US Navy both have, what would seem advanced, roles according to their interpretation of maritime security and the threats in their respective domains. The point being that African navies must first crawl before they can walk, and in doing so create flexible forces that can combat asymmetrical threats and stabilise the littoral regions so needed for economic stimulation. Such a force should be complemented by an African maritime court to provide an effective and stable legal threat to criminals and pirates.

3.6 The Economic Cost of Maritime Piracy

In a period of 5 years (2008-2012) there have been around 1,800 acts of piracy which have caused immeasurable damage and harm to the maritime trading industry and seafarers respectively (ICC International Maritime Bureau, 2012).

The global costs of piracy will be discussed by extracting from a report by Bowden, Hurlburt, Aloyo, Marts and Lee. The report followed a two part structure; Primary (Direct Economic) Cost and Secondary (Macroeconomic) Cost. Primary Costs consist of the direct costs of ransoms, insurance, rerouting, security equipment and military operations. The secondary costs are those associated with a decline in regional trade and the inflation of food prices. This section has been focused on Somali piracy, because the Horn of Africa is the area where piracy is most highly concentrated and is the greatest source of current data and information.

According to Bowden *et al.* (2010, 7) there are three main challenges when it comes to calculating the cost of piracy:

1. Data limitations: Even though an extensive array of data was analysed, some shipping data was still missing. An example of this would be the ransom amounts paid, as shipping companies are reluctant to release such information to dissuade further acts of piracy.

2. Imperfect reporting on piracy: The IMB is generally accepted as the primary source of information on piracy in the world, however, they are restrained by the volume of pirate attacks permitted to report and document. Noel Choong, head of the IMB's Piracy Reporting Centre, reckons about half of all pirate attacks go unreported.

3. Disaggregating effects from general financial instability: The recent global recession makes it difficult to distinguish between the independent impact of piracy and current economic trends, such as reductions on foreign direct investment (FDI), commodity price inflation or tourism.

The following section addresses the main costs of piracy, including: the cost of ransoms, piracy insurance premiums, deterrent equipment, re-routing vessels away from piracy risk zones, naval deployments in piracy hot zones, piracy prosecutions, and organization budgets dedicated to reducing piracy. Lastly, the estimated secondary costs of piracy is discussed followed by an estimation of the total cost.

3.6.1 The Cost of Ransoms

In 2010 the average ransom was predicted to be around $ 5.4 million. Increasing ransoms have led to lengthened negotiations, and therefore the duration seafarers are held hostage, averaging 106 days between April and June in 2010, reaching 150 days in November 2010. The total cost of ransom is estimated to be around double the value actually paid due to a number of factors listed by Bowden *et al.* (2010, 9), such as:

· cost of negotiations,

· psychological trauma counselling,

· repair to ship damage due to lack of maintenance,

· physical delivery of the ransom money, often by helicopter or plane, and

· the costs resulting from ships being held out of service.

To expand on the last point, it would cost around $4.5 million for a cargo ship to be held for 3 months at a charter rate of $50,000 per day using the average holding times mentioned earlier. Bowden *et al.* (2010) concluded that the direct cost of Somali piracy ransoms in 2010 approximated to $480 million, after doubling the calculated costs and excluding the actual ransom paid, which is generally covered by insurance.

3.6.2 The Cost of Insurance

The maritime insurance industry has responded to the growing threat and cost of ransoms by increasing its shipping rates and premiums. Maritime insurance comes in four main types: war risk, kidnap and ransom, cargo and hull insurance (Bowden *et al.*, 2010, 10).

1. War Risk: War Risk insurance is an excess charge for a vessel transiting a "war risk area". The Gulf of Aden was classified as such an area by Lloyds Market Association (LMA) Joint War Committee in May 2008. Since this date, the cost of war risk premiums have increased 300 fold up until 2010.

2. Kidnap and Ransom (K&R): K&R insurance covers crew against ransom demands, but not the vessel or cargo. It is estimated that K&R insurance premiums increased tenfold between 2008 and 2009.

3. Cargo: This insurance covers goods transported by vessels. The excess premium on cargo transiting volatile regions is estimated to have increased by between $25 and $100 per container until 2010.

4. Hull: It covers the physical damage to the ship, including harm from heavy seas, collision, sinking, capsizing, grounding, fire or piracy. Hull insurance is estimated to have doubled in premiums due to piracy.

Bowden *et al.* (2010) assume that 10% of total shipping traffic transiting the Gulf of Aden (total of around 30,000 in 2010) will re-route past the Cape of Good Hope and thus be exempted from these war risk and K&R insurance costs. This percentage was derived from a 20% decrease in Suez Canal revenue of which half is deducted as a result of global economic downturn, meaning 10% of the 20% decrease is a result of re-routing. Of the 90% transiting the high risk areas, Bowden *et al.* then further assume that not all ships will purchase insurance premiums, with a lower bound of 10% and a higher bound estimate of 70% of Ship purchasing insurance. Within these parameters it was calculated that the estimated cost of insurance premiums around the Horn of Africa could be between $460 million (10% lower bound) and $3.2 billion (70% upper bound).

3.6.3 The Cost of Re-Routing

Some vessels opt to avoid the volatile Gulf of Aden, because of their low profile and slow speed, by making the longer or cheaper voyage around the Cape of Good Hope. This can be seen in the 20% decrease of Egypt's Suez Canal revenue. Re-routing ships from Saudi Arabia to the USA via the CSR, adds about 2,700 miles to the voyage. A re-routing from Europe to the Far East will add up to 15 to 20 days for a cargo ship. This excess duration of a single voyage reduces a vessel's annual delivery capacity by 17%. Bowden *et al.* (2010, 12) calculated that if 10% of Suez Canal shipping traffic re-routes as discussed in the previous section, the shipping industry will have to compensate around $2.3 billion to $3 billion per year.

3.6.4 The Cost of Deterrent Security Equipment

Ship owners may also try to attempt to protect their property and crew from pirate attack, whilst reducing their insurance premiums, by equipping their ships and crews with security equipment and training. Anti-piracy gear can include:

· Licensed security guards,

· Long Range Acoustic Devices (LRAD),

· Barbed/Razor wire,

· Electric Fences,

· Slippery Foam systems,

· Nets/Boats Traps, and

· Water cannon/hose systems.

Bowden *et al.* (2010, 15) calculated that the total cost of deterrence equipment for the shipping industry amounts to between $360 million and $2.5 billion, per year.

3.6.5 The Cost of Naval Forces

Over 27 countries contribute to the deterrence of piracy in off the Horn of Africa through the direct deployment of their naval forces. The three main active "anti-piracy" operations are; Operation Atalanta, Operation Ocean Shield and the Combined Task Force (CTF) 151. Operation Atalanta is a European Union initiative launched in 2008 to protect the World Food Program (WFP) vessel en-route to Somalia. Operation Ocean Shield is a NATO operation that assists in regional security, CTF is a multinational task force designed to take assist and succeed operation Ocean Shield (Bowden *et al.*, 2010, 16).

Together, over 43 vessels are operating off the Horn of Africa and the Indian Ocean. With the average US Navy vessel operating at roughly $82,000 per steaming day, the approximate costs of these military vessels are in the area of $1.3 billion per year. Adding in administrative budgets and independent expenditures from other nations, Bowden *et al.* (2010) comes to a rough estimate of $2 billion being spent on military operations in the region.

3.6.6 The Secondary (Macroeconomic) Cost of Piracy

Piracy affects the cost of trade not merely because particular ships are intercepted when delivering goods. As regions are increasingly regarded as unstable, entire trading routes or agreements are altered, insurance premiums increase, cargo ships move to alternative ports to exchange goods (Bowden *et al.*, 2010, 20). These same premiums apply to smaller vessels, such as fishing trawlers, tugs, dhows and luxury yachts which are victimised just as frequently, if not more. A number of nations have indicated that their fishing industry has declined due to the threat of piracy.

The following reports are quoted directly out of a report by Bowden *et al.* (2010, 21) to emphasise the impact of piracy on the fishing industry:

1. Yemen: In 2009, Prime Minister Al Mohammed Mujawar announced that the Yemeni fishing sector had lost $150 million as a result of piracy and armed robbery against vessels.

2. Seychelles: Seychellois Minister for the Environment and Natural Resources, Joel Morgan, has stated that "Maritime attacks [pose] a direct threat to our fishing and tourism industries, the two main pillars of our economy, " reducing the Seychelles economy by around four percent of GDP every year. Impacts on fishery and other sectors are estimated to cost the Seychelles economy up to $10.5 billion per year.

3. Taiwan: According to a Taiwanese delegate at a fisheries meeting in November 2010, more than a third of Taiwan's fishing fleet has been scared off by the threat of piracy. One document stated that 66 of 141 vessels equipped to fish bigeye tuna "have ceased their operations due to the escalating situation."

4. Nigeria: One 2008 study states that over 170 Nigerian fishing vessels were fearful of going to sea due to the piracy risk, threatening approximately 50,000 jobs. It estimates that Nigeria has lost around $600 million in export earnings due to piracy threats to its fisheries.

Some have argued that Kenya bears the economic burnt of piracy in Somalia. The Kenyan Shippers Council (KSC) has estimated that piracy increases the cost of imports by $23 million per month, exports by $9.8 million (both 2010 figures) per month (Bowden *et al.*, 2010, 20).

According to the same report by Bowden *et al.* (2010), "Nigeria's oil industry has been directly targeted by piracy and armed robbery against its ships and oil platforms by local movements protesting the inequitable division of Nigeria's oil wealth. One study calculates that oil production in Nigeria has dropped by around 20% since 2006 as a result of piracy and other attacks.

Royal Dutch Shell reckons that 10% of Nigeria's daily oil output (approximately 100,000 barrels), valuing $1.5 million, is stolen every day. Over the last fifty years, the value of the oil stolen or wasted has amounted to between $300 billion and $400 billion."

Another significant cost to countries located close to unstable and volatile regions affected by piracy, is reduced foreign revenue. The effect of foreign investment comes in multiple forms, the main two concerning piracy would be shipping or transit fees and the loss through reduced tourism.

One straightforward cost is Egypt's loss of revenue, as some vessels opt to re-route around the Cape of Good Hope. The Suez Canal fees range between $200,000 to $600,000 per vessel, depending on their size. Using the 10% estimate of ships re-routing, Bowden *et al.* (2010, 23) calculated that Egypt could be losing up to $642 million per year as an indirect cost of piracy. Noticeable is that revenue from the Suez Canal accounted for around 3.2 % of Egypts GDP in the 2008 fiscal year, making it the country's third largest source of foreign currency.

As mentioned, another way in which foreign investment is reduced is through a reduction in the tourism industry. This is a difficult cost to calculate, largely because it is difficult to determine to what extent tourists would opt for air travel, or what fraction of tourists prefer non-maritime related recreational activities. How do we separate the effects of piracy from the current depressed economic environment? Tourism in Kenya and Yemen seem to be the most severely effected, combining for a loss of around $550 million (Bowden *et al.*, 2010, 23).

3.6.7 Adding up the Costs

As mentioned, this section has focused on Somali piracy, because the Horn of Africa is the area where piracy is most highly concentrated and is the greatest source of current data and information.

Bowden *et al.* (2010, 24) conclude, therefore, that the global cost of piracy is at least $7 to $12 billion dollars per year. This amount does not include actual ransom value paid, as this is generally covered by insurance costs. There are two noteworthy factors that were excluded from the scope of this particular section, note that:

1. Cost of Insurance: As piracy continues to increase across the globe, and insurance against piracy attacks becomes an increasingly lucrative business, we may witness premiums actually decrease as competitors move into the market.

2. Macroeconomic: There are of course certain countries and industries that benefit from piracy. For instance, if foreign investment is reduced in one country as a result of the threat of instability from piracy, that investment may be redirected elsewhere. Or if money saved from re-routing from the Suez Canal ends up paying for more fuel and other transit fees. Thus a complete loss in the shipping industry may be improbable.

3.7 Potential Demand Areas

According to the research found in this section, demand will stem from two main sources; piracy or criminal activity. Demand areas are identified under the assumptions that both piracy and militant activity originates for continental instability of a littoral state. The second assumption is that economic activities will, sooner or later, attract criminals, rebels, terrorists or foreign forces to such unsecured areas of operations. Within this framework, six, present and future areas of interest were identified in the context of maritime security (Figure 3.2).

A brief description of the areas or theatres follows:

1. *Gulf of Guinea*: Oil and gas are important elements in the broader African economy, with a high proportion of oil and gas reserves found offshore, on islands or in coastal areas. These reserves are not enormous, but offer significant quality advantages. Being lighter, oil from the Gulf of Guinea is easier and more economic to refine that Middle Eastern crude. Additionally, the continent's strategic location offers decent sea-lanes to the West and East. The exploration of significant resources on new offshore locations offer a potentially stable security environment, on account of their distance from the mainland. The volatility of landward and coastal oil-producing facilities is well documented. Given the volumes of African oil being lost, estimated at 200 000 barrels per day (some 10% of daily production (Gambrell, 2013)) in Nigeria alone, due to unrest and conflict. Deep offshore location may offer a way around land-based vulnerabilities and represent a major step towards securing oil flows. Neglecting security can thus unleash a potential arc of conflict stretching from Sierra Leone in the west past the Ivory Coast, Nigeria and down to the Republic of Congo, DRC to Angola in the south. The volatility currently found inland will directly affect the adjacent maritime domain as it is not possible to have maritime security amidst such continental insecurity (Vrey, 2009, 92). Moreover, it is assumed that the port of Lagos will serve as support point should the SAN ever participate in sustained operations in the area.

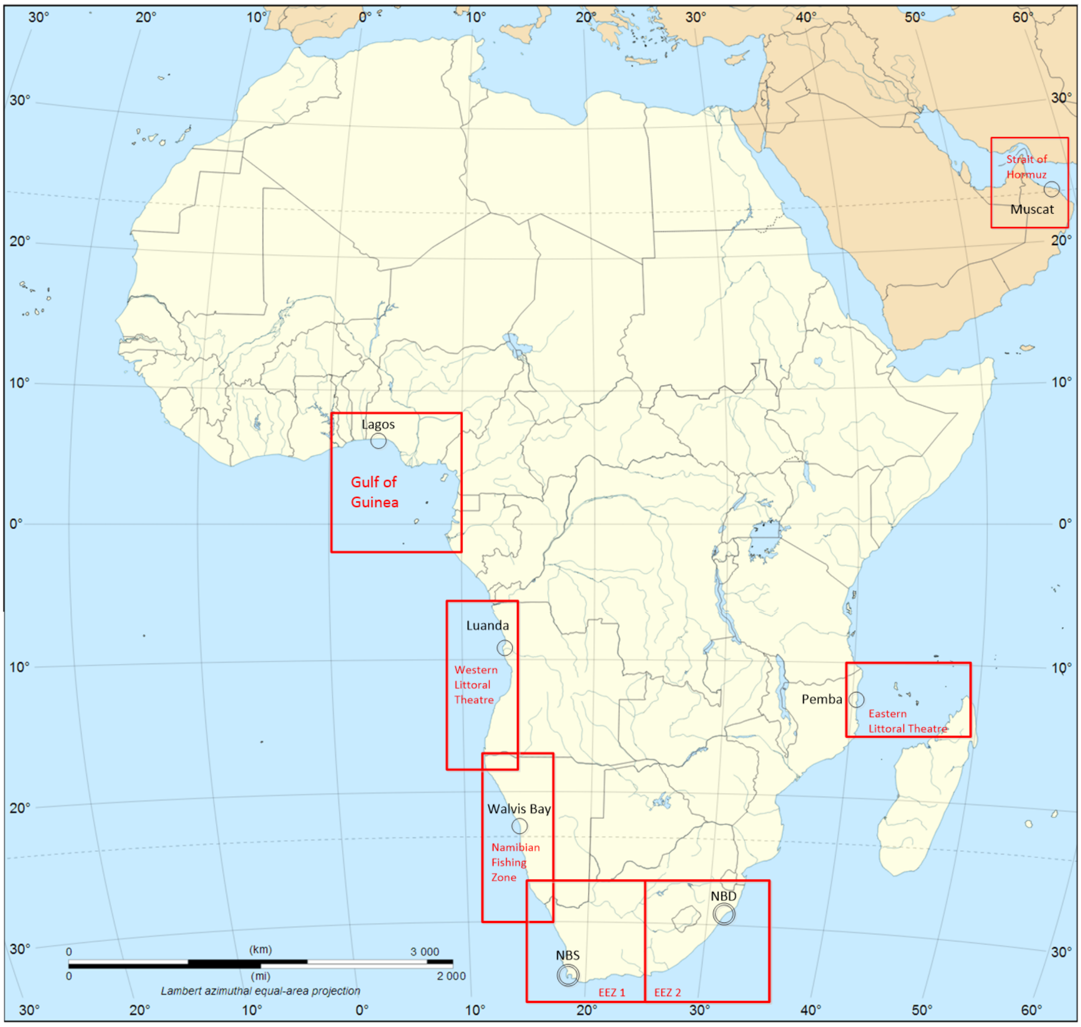


Figure 3.2: Operational Theatres

2. *Western Littoral Theatre (WLT)*: Angola was the world's fastest-growing economy for the first 10 years of the new millennium, averaging a GDP Growth rate of 11.2 percent and reaching an all time high of 23.2 Percent in December of 2007, and it continues to be among the fastest-growing economies on the continent (International Monetary fund, 2012). Angola is Africa's second largest oil producer. As such, oil production is the main sector of the economy, accounting for about 47 percent of total GDP. The majority of Angola's oil production takes place offshore, and for the same reasons as stipulated for the Gulf of Guinea, economic activity combined within an unstable region will attract criminal activity. Given the inadequate capability of the Angolan Navy, it is not unfounded to assume that they will require support should their maritime region

become unstable (Heitman, 2009).

3. *Namibian Fishing Zones*: Although the Namibian Navy has made great strides in the past decade to evolve into an organisation capable of protecting their own interests, they are not there yet. Therefore it is assumed that the SAN will still retain some of its historic responsibility in patrolling the Namibian Fishing Zones.

4. *South Africa's Economic Exclusive Zone (EEZ)*: For obvious reasons, the SAN will be required to patrol and safeguard South Africa's maritime sovereignty. The EEZ includes those territories which comprises of the areas around Marion and Prince Edward Islands.

5. *Eastern Littoral Theatre (ELT)*: Operation Copper has shown that the SAN is capable and willing to take on more regional roles. Piracy in the region north of Pemba has somewhat stabilised since the inception of operation Copper but still remains a present threat (ICC International Maritime Bureau, 2012).

6. *The Strait of Hormuz*: The last potential area of operations is highly unlikely, even more so for a patrol vessel. But war is a reality and presently the Middle east is the hot spot. Should full-scale conflict erupt between Syria and Israel, drawing in Iran who consequently closes the Strait of Hormuz as promised, South Africa would stand to lose 40% of its imported oil (Khan, 2010). The SAN would be forced to take action, even if it only serves to add weight to an international effort to reopen the strait.

3.8 Chapter Summary

This chapter addresses the concepts of maritime security in general as well as in the South African context. Thereafter, the chapter defines the responsibilities of the SAN as a regional naval power, given the inability of most sub-Saharan littoral countries to contribute stability to the maritime domain. Ultimately, Chapter 3 aims to further contextualise the research problem by justifying the increase in demand, which leads to the need to expand capacity.

The first two sections of the chapter convey the physical environment of the SAN and attempts to define maritime security. From these sections it is evident that South Africa is an Economic Island, strategically placed next to the Cape Sea Route (CSR), with a large coastline and Economic Exclusive Zone (EEZ). The second section concludes that maritime security is a wide ranging topic and can only be defined in specific contexts. The German Navy strives for expeditionary capability to secure its trade routes whilst the US Navy strives for global maritime security, mitigating the effects of piracy, weapons proliferation and drug trafficking. In the Southern African context, maritime security includes border patrol, policing and anti-poaching and piracy operations.

The third section covers the economic importance of the African maritime domain. Heitman (2009, 44) provides evidence and insight into the economic potential of the African maritime domain. Offshore oil platforms in the Gulf of Guinea offer a platform for regional prosperity, complementing the offshore mining industry. The fishing industry provides some African countries with the majority of their protein intake whilst contributing significantly to their Gross Domestic Product (GDP).

African countries' inability to pay sufficient attention to their respective maritime domains are discussed in Section 3.5. It concludes that the financial situation of Sub-Saharan Africa as a whole is the main reason most African countries have no real prospects of developing effective naval forces, evident by the fact that Sub-Saharan Africa as a whole has the same GDP as Spain.

Section 3.6 portrays the economic costs of piracy to the maritime trading industry from a report by Bowden *et al.* (2010). The report attempts to add the costs of ransoms, insurance, re-routing via CSR, security equipment and secondary (macroeconomic) costs to an amount of \$ 7 to\$12 billion per year.

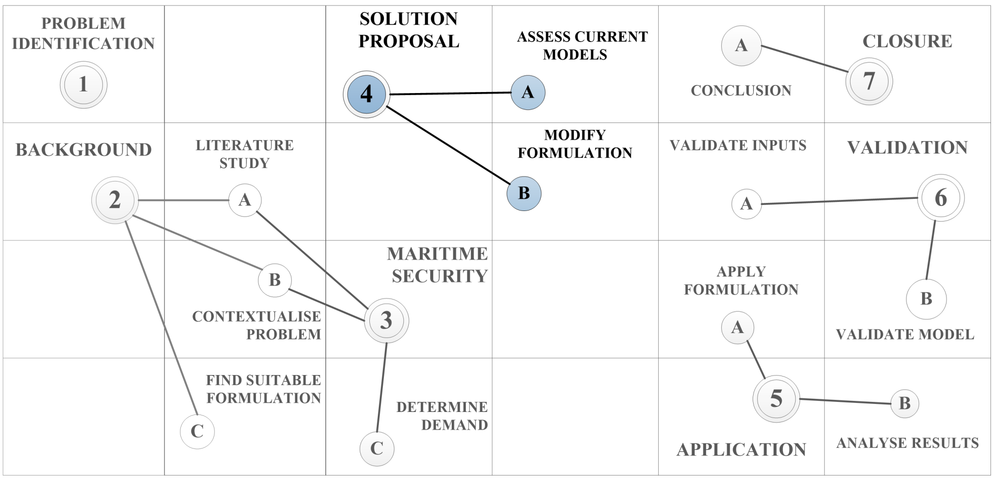
The final section indirectly summarises the previous sections of the chapter and identifies six potential present or future area of interest to the SAN. These areas are; the Gulf of Guinea, the WLT or Angolan waters, Namibian Fishing Zones, South Africa's EEZ, the ELT or Mozambican Channel and the Strait of Hormuz.

Chapter 4

Proposed Facility Location Model

Chapter Aim:

The aim of this chapter is to develop or modify a solution formulation, complementing any multi-criteria location planning method, to solve the research problem by drawing from existing literature.



Chapter Outcomes:

- Motivation of model design.
- Positioning of model in planning process.
- Formulation to solve research objective.
- Plausible assumptions.

4.1 Introduction

Generally military bases have been located with the core criteria of strategic intent, barring logistical constraints. In other words they were placed where they were needed for strategic support depending on whether the delivery of supplies were sustainable. The bases could range in size, complexity and capability, from being a Forward Operating Base (FOB) (which is prone to relocation) to a permanent installation (with large commitments to infrastructure development). More specifically, the locating of naval bases leaves planners with a dilemma as they will always require some form of infrastructure development to support their vessels and crews. Terms such as a FOB could mean nothing more than a berthing opportunity at a foreign port to a naval planner.

The historical approach for naval base locations might have started with the adoption of natural harbours i.e. safe anchor spots. Additionally, these naval bases tended to develop the capability and capacity to provide support only to the vessels stationed or assigned to them. In the subsequent network of naval bases, each strategically contributing to the security domain, this possibly lead to a duplication of services, inefficient utilisation of resources and even an imbalance in facility location. The latter usually resulting in closure or down-scaling of naval bases.

It is therefore evident that past guidelines have failed to consider the principles of facility location. That is, what is the proper combination of naval support bases; and where should these bases be located in order to satisfy the requirements of current and future vessels and comply with economic, social, political and environmental criteria relevant to the region whilst promoting the strategic objectives of the organisation?

The objective is therefore:

an optimal hierarchical facility pattern that would guarantee minimum cost to the organisation regarding its regional and domestic obligations whilst complementing the social benefit of the affected region.

The methodology proposed expands upon existing research and attempts to manage some of the limitations inherent in existing models to formulate a model more capable of solving the objective. Mathematical programming provides the optimisation technique whilst alternative decision models can be used to assess the results with economic, social, political and environmental attributes of the location site.

This chapter will expand upon the logic of the model architecture, derived from the natural flow of research. A general planning framework, based on the model developed, is presented to aid the planner in contextualising the formulation within the planning process. A set of economic, social, political, environmental and strategic factors relevant to the problem are explicitly considered to facilitate proper location planning. The proposed formulation is built and the chapter is concluded with assumptions and expected limitations.

4.2 Model Design and Methodology

From literature it becomes clear that the research problem can be classified as a multi-flow Hierarchical Facility Location-Allocation Problem, which has been widely used and applied (Şahin and Süral, 2007, 2313).The formulation was originally developed by Calvo and Marks (1973) to locate health facilities of different levels whilst assigning populations to the closest facility of their need. Literature by Tien *et al.* (1983) revealed that the original formulation developed by Calvo and Marks was flawed in the sense that it was not *successively inclusive* as stated and they went on to publish an improved model.

Further research showed a shifting focus towards coherent[1] hierarchical models such as the PQ-median problem developed by Serra and ReVelle (1994). The PQ-median problem seeks the location of hierarchical facilities and, at the same time, districts the demand areas to utilise these facilities. It is especially noteworthy when demand areas are equally distanced between two higher level facilities.

After Serra and ReVelle, the only major contributions to the field of hierarchical facility location has been in the areas of reverse flow models and improvements in algorithms (Şahin and Süral, 2007, 2329-2327). The PQ-median formulation will not be applicable to this study as coherency is not always possible, nor always sought, in the problem domain due to economic principles or maritime operations. In other words, vessels will most likely receive level one service inside the theatre of operations, however, due to political or economic reasons, they will not be able to justify receiving higher levels of service in the same area. As a consequence, the foundation of the proposed model will be developed from the formulations of Calvo and Marks (1973) and Tien *et al.* (1983).

Owen and Daskin (1998) reviewed the location problem in the context of strategic planning, classifying models according to the static, dynamic and stochastic nature of the time component (Şahin and Süral, 2007, 2310). Particular focus is given in literature to the risky nature of real-world location problems. Owen and Daskin (1998) classifies two types of models, namely

[1]Coherence requires that an entire area assigned to a facility at one level must be assigned to one and the same facility at a higher level of the hierarchy.

dynamic and stochastic, each attempting to quantify uncertainty through different approaches. Dynamic models assume that the input parameters are known valuables that change deterministically with time. Stochastic models assume that parameters are uncertain or unknown and even relatively certain parameters might be presented as probabilities.

It is the uncertain, resource constrained environment of this study that motivates the favouring of stochastic models above the dynamic approach. As cited in Section 2.2, the stochastic literature is divided into two classes; that which explicitly considers probability distribution of uncertain parameters, and that which captures uncertainty through scenario planning. As mentioned in the delimitation of this thesis, the scope does not permit the additional complexity and the timely collection of data that accompanies probabilistic models. As motivated by Snyder (2006, 538), scenarios provide more tractable models and have the advantage of allowing parameters to be statistically dependant, which is necessary to model reality since entities rarely function in isolation. Moreover, the scenario planning approach has demonstrated success and rigidity in determining fire station locations in Barcelona across different traffic times, by being applied to the P-median formulation by Marianov and Serra (1998).

In summary, the model design endeavours to integrate the hierarchical facility location-allocation formulation developed by Calvo and Marks (1973), and improved by Tien *et al.* (1983), with the scenario or regret-based modification developed by Marianov and Serra (1998). Ultimately leading to:

an optimal hierarchical facility pattern that would guarantee minimum cost to the organisation regarding its operational obligations under all sets of possible future realisations.

4.3 Location Planning Process

As mentioned, the model proposed in this section relies on the model designed by Calvo and Marks (1973, 420), to be used as a decision aiding tool for alternative support or maintenance facility location options. It is not intended as a replacement to the decision making process. The results of this model may be optimal in reference to the model variables, however, it may not be feasible or efficient in terms of the social or political factors encountered in the real world. Therefore this model should be seen in a general framework as depicted in Figure 4.1.

Yang and Lee (1997, 241) state that facility location problems usually start with the recognition of a need for additional capacity, i.e. recognising a need to

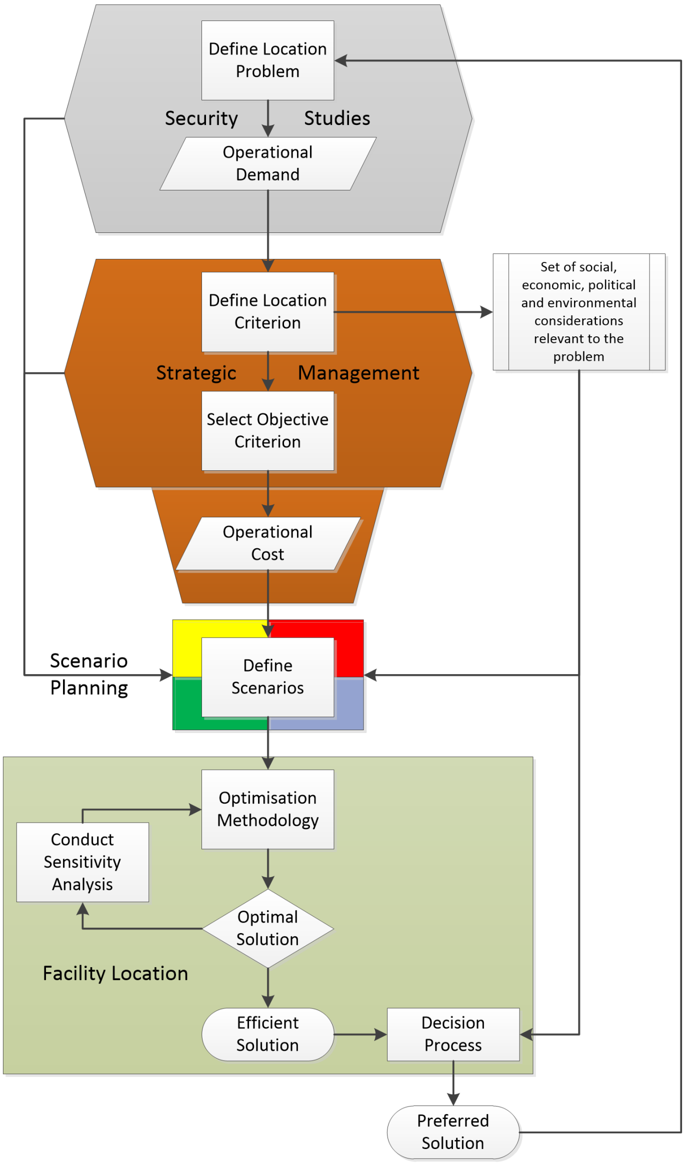


Figure 4.1: Support facility location planning process.

satisfy growing demand. It is therefore logical to derive and define demand in the maritime security context of the location problem. Consequently, the planning process is initiated with the definition of the location problem, focusing on defining operational demand within the planning environment. From this a set of relevant location criteria, bearing in mind the principles of strategic management, is formulated. Some criteria will be of a more social, economic, political, environmental or strategic nature. These criteria should be considered later or independently, in another decision process, resulting in a preferred solution as shown in Figure 4.1.

Subsequently, according to the nature of the problem an objective criterion is selected for optimisation. For instance transit distance or transit time can be selected for emergency services or facilities in rural areas. Similarly, costs to users becomes important when location health facilities in low-income areas. In the scope of this thesis, the objective function is to minimise transit time across all the operational theatres, which leads to a decrease in hours at sea and directly increases hours in theatre (hence utilisation). The objective function includes fixed and operating cost formulations for each type h location to determine if locating such facilities justifies the decreases in transit time, consequently minimising total operational cost across the upkeep system.

Once operational demand and relevant theatres are defined, they can be incorporated into the scenario "Game Board" model proposed by Sunter (2012) in Section 2.4. This extension model will be driven by distance and demand, thus each quadrant will have a scenario relating to high or low distance and demand. It is important to note that the drivers for the scenarios can be independent from the optimisation model, as long as the attributes of each scenario are relevant to the optimisation formulation. An example would be a scenario board where the drivers are environmental. One driver could be the leniency of environmental law (scaled) and the other fuel efficiency of the vessels. The escalation of environmental law combined with inefficient vessels can create one of the scenarios that result in some added factored cost to transiting with inefficient vessels, thus the attributes are still relevant to the formulation.

Combining the objective function with the scenario model parameters, within the proposed facility location formulation, results in an optimal solution relevant to the chosen criteria across all scenarios. Afterwards, its sensitivity to changes in parameters and constraints can be analysed. This process is repeated until the most sensitive parameters are rigid and accurate. These sensitive parameters would in some cases represent "Flags", indicating a movement from one scenario to another when they change, resulting in the redistribution of scenario probabilities. The planner can now add the "efficient solution" to any another decision process to determine the "preferred solution". If the preferred solution is not obtained, the cycle may be repeated by changing or selecting another objective criterion, thus generating an alternative efficient solution. The process stops when the "preferred solution" is obtained, or when budget or time limits are reached.

Not only does this model provide a systematic method to obtain the "preferred" location, it can convey three managerial strategies by modifying the initial formulation. First, the original model minimises system cost across all the scenarios; second, the model can minimise regret across all scenarios, i.e. minimising the system cost in the worst case scenario; and lastly, each scenario can be weighted according to their chance of occurring.

4.4 Proposed Model

The optimisation problem involves the location of a support facility in a region so as to minimise cost across different scenarios k. A generalised support infrastructure consists of s facility types, more specifically naval bases, each providing level of services h (for h = 1,2,...,s). The "successively inclusive" property, that applies to naval bases, requires that higher level facilities must provide all of the lower level services. The relevant maritime region is clustered into n operational theatres. Any vessel operating in such a theatre would require three (h=1,2,3) levels of service, denoting First, Second and Third Line maintenance levels, at specified intervals over a certain period. For instance, a vessel operating in a designated theatre i will return to its stationed facility in area j or i more frequently for First Line (h =1) maintenance than for Second (h =2) or Third Line (h =3) maintenance.

The goal being determining the optimal hierarchical maintenance network between all facilities considering the financial constraints and operational obligations, future and present, of any organisation operating patrol vessels, including which theatre(s) should be served by each facility in the optimal solution.

4.4.1 Demand

Demand or services required by each theatre will depend on the type and number of vessels patrolling in the area due to certain objectives, either purely military or political. Some manipulation is thus required to convert time in theatre to some measurable demand. This problem is addressed by extracting, from usage and upkeep plans for patrol vessels, the amount of times a vessel will need to return to some facility of level h from area i over a certain time period.

Therefore, let a_{ih} be the number of times a vessel a, operating in theatre i, requires service or maintenance of level h within a certain period according to the programmed usage and upkeep plans. The total demand of vessel(s) a in theatre i is given by:

$$a_i = \sum_{h=1}^{s} a_{ih}, \tag{4.1}$$

For instance, assume that according to the 5 year usage and upkeep plan for a particular vessel, they are required to return to a Level 2 (Second Line, h =2) maintenance facility once every 21 weeks for 3-4 weeks. Furthermore they require Level 3 (Third and Fourth Line, h =3) maintenance once every 104 weeks (2 years) for 10 weeks. Thus, over a 5 year period, the demand will be the following for one vessel with an endurance of 21 days in theatre i; a_{i1}

= 10 if the vessel is patrolling for 4 months each year; $a_{i2} = 4$ and $a_{i3} = 1$ as stipulated in Table 4.1.

Table 4.1: An example of 5 year demand for patrol vessels.

Level	Frequency	Duration	Interval	Additional
III	1	10	104	Assuming the vessel has to return to a Level III facility once every two years for preventative maintenance and the repair of essential defects.
II	4	3-4	21	Assuming the vessel will need to be alongside for 3-4 weeks in a facility with Level II capability to assist in maintenance.
I	10	1	16	Assuming the vessel conducts one 4 month patrol each year, requiring 5 Level I services during each deployment. A maximum of two deployments per year is possible.

While the costs or conditions under which a facility will operate may be estimated with some degree of certainty for the short-term, the long-term and operating costs are subject to considerable uncertainty.

Through Marianov and Serra (1998, 384) and Daskin *et al.* (1997, 227), the model recognizes uncertainty in:

1. *Transport unit prices.* The cost of operating a vessel per hour can vary during the course of its lifespan. Factors such as age, cost of fuel, change in environmental laws or sailor salaries can influence the cost of operating a vessel.

2. *Demand.* The number of vessels required at the nodes (theatres) of the network. That is, the number of vessels required in each theatre is not a known quantity but can assume different value depending on the their capability, mission and configuration among other factors; and/or

3. *Variance.* Transit times can have different values depending on the weather or other factors, but these deviations will be irrelevant in the context and scope of this thesis.

4. *Technology.* The influence of technology on the operating or maintenance procedures of the organisation.

5. *Land Availability.* Some future opportunities will be lost due to the decreasing availability of open sites to locate potential facilities.

6. *Management Approaches.* Changes in policy or managerial approaches cannot be estimated and is therefore also treated as an uncertainty.

To deal with uncertainty regarding future costs and operating conditions, planners often define a number of possible future scenarios. Facility locations that perform well with respect to all of the scenarios can then be identified. Consequently, the proposed model will make use of the scenario approach to quantify uncertainty.

4.4.2 Minimisation of Distance

Using transit time as location criteria, the objective is to minimise the weighted distance or transit time throughout the planning region. The proposed model focuses only on minimising transit distances to theatres, not the time spent in theatre, although there are dependencies. Utilising vessels' maintenance demand as multipliers, the total nautical miles from theatre i to facility j of service of level h is given by $a_{ih}d_{ij}$. The objective function for minimising distance retains the original form of:

$$\text{Minimise} \left\{ Z = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} \sum_{h=1}^{s} a_{ih} Y_{ijh} \right\} \tag{4.2}$$

Decision variables:

$$Y_{ijh} = \begin{cases} 1 & \text{if } h \text{ level maintenance of vessel in area } i \text{ is assigned to area } j \\ & \text{where a type } h \text{ facility is,} \\ 0 & \text{if no assignment takes place.} \end{cases}$$

subject to:

$$\sum_{j}^{n} Y_{ijh} = 1 \quad \forall i, h, \tag{4.3}$$

$$Y_{jjh} \geq Y_{ijh} \quad \forall i, j, h, \tag{4.4}$$

$$Y_{jjh} \geq Y_{jjh+1} \quad \forall j, h, \tag{4.5}$$

$$\sum_{i=1}^{n} Y_{iih} = \sum_{r=h}^{s} m_r \quad \forall h, \tag{4.6}$$

$$Y_{ijh} \in \{0, 1\} \quad \forall i, j, h. \tag{4.7}$$

where notation is defined as follows:

i	=	index of demand nodes
j	=	index of potential facility sites
s	=	total types of facilities (or services)
n	=	total number of locations
a_{ih}	=	demand in location i requiring type h facility or service
m_h	=	number of type h facilities to be located
d_{ij}	=	distance from demand area i and area j

The constraints are of a similar nature to the constraint set of the hierarchical location formulation found in Section 2.1.3 and assumes that all demand points are also potential facility sites. The first and second set of constraints, (Equation 4.3) and (Equation 4.4) provide that each demand level h in location i is assigned to a facility of type h in location i or j whilst avoiding the possibility of assigning individuals residing in location i and requiring type h service to location j where no such service is available. The third constraint, (Equation 4.5) forces the formulation to locate lower level facilities in location j if a higher level facility was located in area j. Set (Equation 4.6) specifies the total number of facilities, by type, that can populate the solution space. The final constraint is a binary requirement for the problem variable (Tien *et al.*, 1983, 1129).

An graphic example of a feasible solution implied by the above formulation is depicted in Figure 4.2 adopted from Calvo and Marks (1973, 413).

Table 4.2: Example of Building locations.

Facility Type	**Area**
I	1 and 4
II	3
III	5

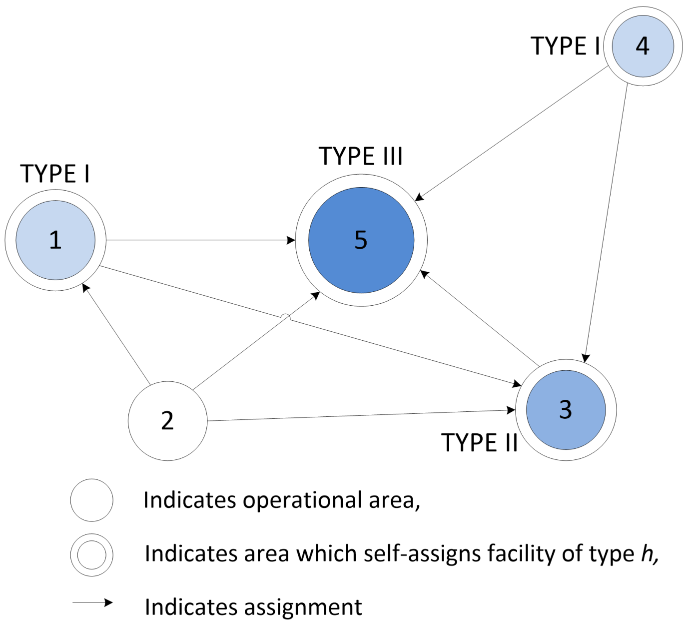


Figure 4.2: Example diagram of a feasable solution.

Table 4.3: Example of Assignments.

Area	**Group**	**to Area**
1	II	3
1	III	5
2	I	1
2	II	3
2	III	5
3	III	5
4	II	3
4	III	5

4.4.3 Minimisation of Cost

A concurrent objective is to minimise total cost of the maintenance system. Transit costs are one of the primary expenditures in getting to an operational theatre, hence minimising transit time will directly increase patrol time in the designated theatre. Transit costs c_{ij} will be the sailing distance divided by the speed z in knots, thus giving hours in transit or at sea. The cost per hour per vessel (x_c) is a known variable, consequently, the transit costs can be determined through Equation 4.8.

$$c_{ij} = \frac{d_{ij}x_c}{z} \tag{4.8}$$

The total transit cost (TC) for the planning region is:

$$TC = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} \sum_{h=1}^{s} a_{ih}Y_{ijh} \tag{4.9}$$

Capital and operating expenditures are dependent on the initial development and daily functioning of the facility. Therefore the following principal cost elements are included:

F_{jh}	=	fixed cost of building or expanding facility of type h in area j
V_{jh}	=	unit cost of operating facility of type h in area j

Consequently, the total facility system cost (FC) assumed by region is (Calvo and Marks, 1973, 414):

$$FC = \sum_{j=1}^{n}\sum_{h=1}^{s} F_{jh}Y_{jjh} + V_{jh}\sum_{i=1}^{n} a_{ih}Y_{ijh} \tag{4.10}$$

Combining transit and facility costs, (Equation 4.9) and (Equation 4.10) respectively, the total system cost can be minimised. The objective function takes the form:

$$\text{Minimise} \quad \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}\sum_{h=1}^{s} a_{ih}Y_{ijh} + \sum_{j=1}^{n}\sum_{h=1}^{s} F_{jh}Y_{jjh} + V_{jh}\sum_{i=1}^{n} a_{ih}Y_{ijh} \tag{4.11}$$

4.4.4 Minimising Transit Time Across Scenarios

In 1998, Marianov and Serra introduced the concept of regret to the P-median facility location formulation when locating fire stations in Barcelona (Spain). They converted uncertainties into scenarios, which they called “changing networks”. Basically, uncertainty was treated by realising different demands and travel times in different scenarios. The motivation and formulation for this approach can be found in Sec 2.2.

This model will attempt to combine the formulation of Calvo and Marks (1973), improved by Tien *et al.* (1983), with the scenario formulation of Marianov and Serra (1998). The reasons for this, as stated by Ring and Perry (1985) and Poister and Streib (1999), are that public organisations would do better to be prepared for any eventuality to some degree. Demand in each theatre is directly dependant on the situation, i.o.w. stability, of that specific region.

In the same sense, the stability of a region is dependent on a large number of factors, ranging from social, economic, political through to environmental. It is outside the scope of this thesis to accurately predict demand for each region.

Therefore, based on the expert opinions of SAN officers, and considering the limited number of vessels at their disposal, the maximum demand can be subjectively determined for each region according to different scenarios. As a consequence, only demand will change in each scenario, determining the need for the patrol vessels in each scenarios such as: escalated piracy in Gulf of Guinea, requiring patrol vessels in the area; the closing of the Strait of Hormuz by Iran, requiring frigates to participate in securing South Africa's oil supply from the Persian Gulf, leaving the patrol vessels to extend or change their obligations.

Through combining the improved hierarchical location function of Tien *et al.* (1983) and scenario application formulation from Marianov and Serra (1998), (4.11) and Section (2.2.2.2) respectively, the total system cost can then be minimised across all scenarios. The objective function of this thesis can thus be formulated as follows:

$$\text{Minimise} \qquad \{\, M \,\} \tag{4.12}$$

Decision variables:

$$Y_{ijhk} = \begin{cases} 1 & \text{if } h \text{ level maintennce of vessel in area } i \text{ is assigned to area } j \\ & \text{where a type } h \text{ facility is located under scenario } k, \\ 0 & \text{if no assignment takes place.} \end{cases}$$

subject to:

$$\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ijk} \sum_{h=1}^{s} a_{ihk} Y_{ijhk} + \sum_{j=1}^{n}\sum_{h=1}^{s} F_{jh} Y_{jjhk} + V_{jh} \sum_{i=1}^{n} a_{ih} Y_{ijhk} \leq M \quad \forall k, \tag{4.13}$$

$$\sum_{j}^{n} Y_{ijhk} = 1 \quad \forall i, h, \tag{4.14}$$

$$Y_{jjhk} \geq Y_{ijhk} \quad \forall i, j, h, \tag{4.15}$$

$$Y_{jjh} \geq Y_{jjh+1} \quad \forall j, h, \tag{4.16}$$

$$\sum_{i=1}^{n} Y_{iihk} = \sum_{r=h}^{s} m_{rk} \quad \forall h, \tag{4.17}$$

$$Y_{ijhk} \in \{0,1\} \quad \forall i,j,h,k. \tag{4.18}$$

where notation is defined as follows:

k	=	index of scenarios
s	=	total types of facilities (or services)
n	=	total number of locations
a_{ihk}	=	demand in location i requiring type h facility or service under scenario k
m_{hk}	=	number of type h facilities to be located under scenario k
F_{jh}	=	fixed cost of building or expanding facility of type h in area j
V_{jh}	=	unit cost of operating facility of type h in area j

The first constraint (4.13) is directly related to the main objective function, that is finding the minimum cost in servicing demands when all scenarios are evaluated. The left side of the constraint represents the total cost function in the corresponding scenario. The objective of the model is to minimise M, which is the same in each constraint. That is, the model aims to find a set of locations that minimises the largest transit costs (travel distance) in each scenario. The rest of the constraints are of a similar nature as the constraint sets of the hierarchical location formulation found in sections 4.4.2 and 4.4.3.

4.4.5 Minimising Regret and Weighing Scenarios

If the objective is minimising regret, the constraint set (4.13) is replaced by the following:

$$\begin{aligned} &\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ijk} \sum_{h=1}^{s} a_{ihk} Y_{ijhk} + \sum_{j=1}^{n}\sum_{h=1}^{s} F_{jh} Y_{jjhk} \cdots \\ &\cdots + V_{jh} \sum_{i=1}^{n} a_{ih} Y_{ijhk} - Z_k \leq M \quad \forall k, \end{aligned} \tag{4.19}$$

where Z_k is the optimal objective value for each scenario. The value is found by applying the original formulation (4.11) to each scenario individually. The unknown variable symbolises the largest regret evaluated across all scenarios. This method is used in strategic management if one of the scenarios depicts absolute disaster for the organisation, therefore the potential of the other scenarios must be sacrificed to mitigate the effects should this ruining scenario realise.

Note that in the models presented, each scenario is weighted equally. Both minimax and regret formulations can be modified to account for the situation where scenarios have different weights (read probabilities). In this case constraints (4.13) and (4.19) can be modified as follows (Marianov and Serra, 1998, 393):

$$\beta_k \Bigg(\sum_{i=1}^{n} \sum_{j=1}^{n} c_{ijk} \sum_{h=1}^{s} a_{ihk} Y_{ijhk} + \sum_{j=1}^{n} \sum_{h=1}^{s} F_{jh} Y_{jjhk} \cdots \\ \cdots + V_{jh} \sum_{i=1}^{n} a_{ih} Y_{ijhk} \Bigg) \leq M \quad \forall k, \tag{4.20}$$

$$\beta_k \Bigg(\sum_{i=1}^{n} \sum_{j=1}^{n} c_{ijk} \sum_{h=1}^{s} a_{ihk} Y_{ijhk} + \sum_{j=1}^{n} \sum_{h=1}^{s} F_{jh} Y_{jjhk} \cdots \\ \cdots + V_{jh} \sum_{i=1}^{n} a_{ih} Y_{ijhk} - Z_k \Bigg) \leq M \quad \forall k, \tag{4.21}$$

where β_k denotes the weight or probability assigned to each scenario k. These probabilities can be adjusted as relevant "flags" (Sec. 2.4) go up throughout the planning process.

4.4.6 Assumptions and Limitations

The model operates under certain assumptions, be they of a functional nature or purely about input behaviour. These assumptions need to be recognised in order to place the model in proper context. Consequently, the following modified assumptions from the Calvo and Marks (1973) formulation also hold for this model, classified in categories pertaining specifically to the Model, Inputs and Costs.

1. *Model:*

   a) The assignments in the proposed model are complete, no partial assignments are allowed. That is service demand h, in theatre i, is completely assigned to a h-type facility, permitting no future variation.

   b) There is no referral to a higher level facility after initial assignment, meaning a ship on a routine 2nd Line berthing will not be referred to a 3rd Line facility if some external problem is detected.

c) Since the distances are not scenario-dependent, c_{ijk} and Y_{ijhk} is replaced by c_{ij} and Y_{ijh} throughout the formulation, thereby significantly reducing the number of decision variables (Daskin *et al.*, 1997, 235).

d) Vessels go to the closest appropriate facility of type h for level h maintenance.

e) All maintenance facilities offer lower level maintenance.

f) All maintenance levels are alike, irrespective of the facility.

2. *Inputs:*

a) The demand a_{ih} in theatres is presented deterministically although they are considered stochastic by the model through the scenario approach.

b) Movement or creation of new demand theatres is not considered. For example, if piracy should escalate north of the ELT and consequently justifies the SAN operating more to the north, the ELT will not be able to move nor will a new theatre be created.

c) The distance is fixed between theatres and taken as the distance between the main harbours in each theatre.

d) The economic transit speed of the vessel will be constant.

3. *Costs:*

a) The operating cost of a BIRO OPV is R790 000 per day sailing, derived from the operating cost of Sarah Baartman environmental protection OPV.

4.5 Chapter Summary

The aim of this chapter is to identify or develop a theoretical mechanism or formulation capable of solving the research question. For that reason, Chapter 4 proposes a model that combines existing hierarchical formulation from Calvo and Marks (1973) and Tien *et al.* (1983) with scenario based formulation from Marianov and Serra (1998).

The chapter begins with a contemporary, military focused, facility location outlook which stretches back to the initial inception of naval bases centred on the location of natural harbours. It discusses the impact of the two main drivers for facility location in the past, namely strategic importance and the need for numerous independent capabilities. The untimely convergence of these two factors have led to naval installations in inefficient locations relevant to each other and possibly possessing obsolete or duplicate capability.

The second section clarifies the methodology used to identify the appropriate literature and explains the design reasoning and process. The methodology reveals that formulation by Calvo and Marks (1973) can be used as the foundation for a proposed model to solve what has been classified as a *multi-flow hierarchical facility location-allocation problem* (Şahin and Süral, 2007). After improvements by Tien *et al.* (1983) were incorporated into the basis formulation of Calvo and Marks (1973), the problem of uncertainty regarding inputs was addressed. Scenario or regret based formulation developed by Marianov and Serra (1998) was added to the proposed model to more accurately incorporate the inherently uncertain aspects of the research problem, to ultimately produce:

an optimal hierarchical facility pattern that would guarantee minimum cost to the organisation regarding its operational obligations under all sets of possible future realisations.

The following section contextualises the proposed model in reference to a more complete location planning process. It attempts to illustrate the conception of demand inputs and the role of location factors in the planning process as a whole. The section aims to clarify that the formulation will produce an *optimal solution*, but not necessarily a *preferred solution*, if not used in conjunction with the external location factors in another decision making process, such as the Analytical Hierarchy Process (AHP).

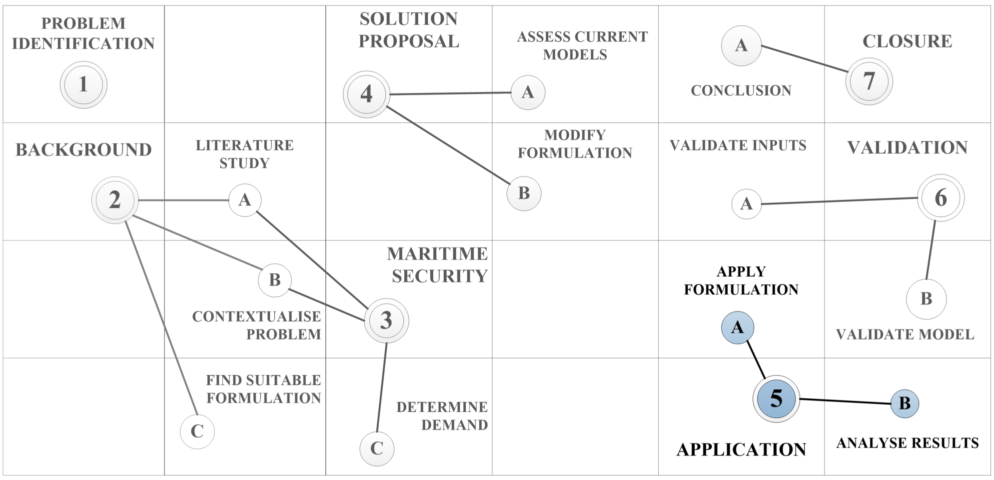
The fourth and final section constructs the proposed formulation in different subsections, starting with defining demand in a manner more specific to the naval environment. By extracting, from usage and upkeep plans, the amount of times a vessel will need level h service over a given period, the demand for each level of service can be determined. In the subsequent subsections, formulations used to minimise distance is converted into a minimisation of cost formulation, adding fixed and operating cost. Lastly, the assumption and limitations pertaining to the proposed model are stated.

Chapter 5

Case Study

Chapter Aim:

The aim of this chapter is to utilise the previously developed facility location formulation in a specific case study in order to solve the research objective.



Chapter Outcomes:

- Introduction of case study.
- Introduction of case specific definitions and terms.
- Conception of plausible future scenarios.
- Solution of research objective.
- Sensitivity analysis of results.

5.1 Introduction

The South African Navy (SAN) intends to reinstate Naval Station Durban (NSD) as a fully operational support and training base for the planned acquisition of a new class of Offshore Patrol Vessels (OPVs). A support base located in Durban could better serve anti-piracy patrols in the ELT as it would be closer to the theatre of operations. The support structure of the SAN consists of different levels of maintenance or upkeep, similar to the hierarchical services provided by medical healthcare facilities. These levels of services are denoted in Section 5.2.

The objective therefore lies in determining the optimal hierarchical maintenance network between SMST and Durban considering the financial constraints and operational obligations, future and present, of the SAN, including which theatre(s) should be served by each facility in the optimal solution. Furthermore the allocation of facilities to specified theatres should be conducted so as to satisfy the social and security needs of the region if possible.

Chapter 5 proposes to incorporate the demand areas defined in Chapter 3 into the formulation proposed in Chapter 4, within the context of the research question. Consequently, attempting to find an optimal pattern or network of facilities of different levels to minimise the total cost of ownership in supporting a new class of patrol vessel.

5.2 Operational and Maintenance Doctrine

To ensure that SAN vessels are able to meet the operational demands expected of them with minimum outside assistance it is essential for hulls and equipment to be maintained in a fully serviceable condition. For this reason, operational programmes are executed to enable the required balance between material maintenance, personnel training and operation requirements to be achieved. The aforementioned should apply whilst providing for maintenance periods in harbour between operational periods. The carrying out of major repairs of vessels exist in the form of the 2 Year Hull Availability Program (HAPRO), and 5 Year Major Upkeep Plan (MUP) programmes. The following periods are allocated for the execution of planned maintenance:

a. Self Maintenance Period (SMP).

b. Assisted Maintenance Period (AMP).

c. Docking and Essential Defects (DED).

d. Refits.

5.2.1 Definitions

This section contains definitions and terms relevant to the formulation of the location model, as well as maintenance in the maritime, or more specifically, naval context (South African Navy, 2008).

1. AMP. An AMP is a scheduled upkeep period during which the Fleet Maintenance Unit (FMU) provides assistance to the Ship's Staff with maintenance and repair work, as well as the carrying out of predetermined Engineering Changes (ECs), in accordance with the Upkeep/Usage plans.

2. DED. DEDs are scheduled periods in which a vessel is given a routine intermediate docking and during which certain specified preventative maintenance and essential defects directly affecting fighting and seagoing efficiency, which cannot await the next refit, are undertaken. The DED are timed to take place approximately midway between Refits. The support of uniformed personnel from the FMU will be provided to assist the Ship's Staff with maintenance under Dockyard coordination.

3. Dockyard. ARMSCOR DOCKYARD will be referred to as "Dockyard" in accordance with The Dockyard Transfer Agreement for the Naval Dockyard Simon's Town.

4. Engineering Change (EC). An EC is an alteration to the baseline of a system or item as defined in its data pack that would alter in any way the system's or item's operational performance, construction, design, configuration, interchangeability or support.

5. HAPRO. The HAPRO indicates the planned frequency and duration of Refits, DEDs and AMPs for SAN vessels over a two year cycle as derived from the MUP.

6. Major Upkeep Plan (MUP). The MUP indicates the frequency and duration of Refits and DEDs for SAN vessels over a five year cycle.

7. Refit. A scheduled period when corrective and preventative maintenance is carried out by Ship's Staff and Dockyard. ECs may also be undertaken if authorised by the Chief of the Navy.

8. SMP. A SMP is a scheduled upkeep period to enable the Ship's Staff to carry out maintenance and repair work using their own facilities and resources, in compliance with the Usage/Upkeep Plans.

9. Upkeep. The term "Upkeep" embraces all actions which contribute to the ability of the SAN to achieve the highest degree of seagoing and fighting efficiency. The upkeep of SAN Vessels and equipment involves

servicing at sea by Ship's Staff, maintenance alongside by Ship's Staff whilst assisted by the FMU personnel and Refitting by the Dockyard and Contractors.

5.2.2 Levels of Maintenance

The support structure of the SAN consist of providing vessels with incremental levels of support and at different depths. The following extracts from the SAN's Logistical Manuals provide the official definitions and purpose of these service levels.

Maintenance Levels (South African Navy (2008)):

a. First Line. First Line is the maintenance organisation immediately responsible for both the preparation for operation and the initial diagnosis of defects of vessels, their systems and equipment. First Line will denote Ship's Staff doing maintenance tasks.

b. Second Line. Second Line is the maintenance organisation established to provide support for vessels and their systems for which facilities do not exist onboard the vessel to carry out maintenance and repairs. Second Line will denote the FMU.

c. Third Line. Third Line is the maintenance organisation within the Naval Service to provide support for the vessels and their systems, but excluding the organisation within the First or Second Line. Third Line implies workload for which no facilities or expertise exist within the FMU. Third Line will denote Dockyard, Workshops of the Naval Stores Depot and Armament Depot.

d. Fourth Line. Fourth Line is the private organisation providing repair, modification and reconditioning/overhaul of vessels and their associated equipment for which the facilities, expertise or resources are not available within the SAN. Fourth Line will denote Contractors.

5.2.3 Upkeep and Usage Plans

The purpose of Upkeep Programmes is to maintain vessels according to the Usage/Upkeep Plans for SAN Ships and Submarines that determines the type, frequency and duration of the upkeep for each SAN Vessel. The Upkeep Programmes take the operational requirements and resource limitations of the vessels into account.

5.3 Data Inputs

The model receives data in the form of scenario sets, each with its own demand values for specified areas. In other words, distances between theatres do not change between scenarios, but demand could be high in one theatre in a given scenario and then zero in the next scenario for the same theatre. For fixed and operating cost, the inputs for all scenarios are the same, this is due to the method used to craft the scenarios. The method makes use of a scenario Game Board approach, placing scenarios in quadrants divided by driver axes. The driver axes for the scenario inputs were distance and demand (Figure 5.1), both directly influencing the transit cost of the model.

5.3.1 Demand Data

Demand for each level is derived from the usage and upkeep plans for each class of vessel. A projected usage and upkeep plan for the BIRO vessels is presented in Table 5.1.

Table 5.1: Projected usage and upkeep for BIRO vessels.

Action	Level	Duration	Interval	Unit
Resupply	I	1	3	weeks
SMP	I	1	16	weeks
AMP	II	4	21	weeks
DED	III	10	104	weeks
Refit	III	33	260	weeks

From Table 5.1 the demand frequencies can be derived. This is, however, not achieved without some simplifying assumptions. Firstly, it is assumed that resupplying the vessel will take one week. Secondly, the one week required for SMP will be absorbed within such a resupply week, basically meaning the SMP will be executed on a resupplying opportunity. Additionally, the refit period includes 5 weeks necessary for Harbour Acceptance Trails (HATS) and Sea Acceptance Trails (SATS). Lastly, *low demand* is defined as one 4 month deployment to a theatre per annum, *high demand* as two 4 month deployments per annum and ultra demand consists of continuous deployment (3 deployments per annum). The final result of the derivation is shown in Table 5.2. Note that the demand frequencies exclude corrective maintenance, they are only an approximation of preventative demand.

Table 5.2: Projected 5 year demand frequency from BIRO patrol vessels.

	Demand Frequency		
Level	**Low**	**High**	**Ultra**
I	20	40	60
II	10	10	15
III	3	3	3

5.3.2 Scenarios Inputs

The presented demand scenarios were validated, as possible future realisations for the SAN, in Chapter 6. Each scenario has its own demand values for specific demand areas (Figure 5.2). In this section the scenarios will be presented with their derived data sets.

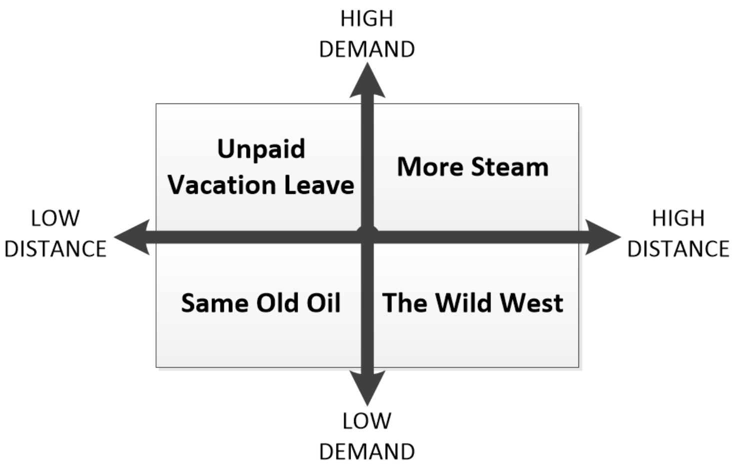


Figure 5.1: Case study Game-Board

1. *Unpaid Vacation Leave*: This scenario is based on the assumption that piracy continues to be a threat in the Mozambican Channel for the next 10 -15 years. This persistence will motivate a need for increased patrol capability, contributing to the motivation for “Project BIRO”. This scenario is placed in the high demand quadrant as continuous patrolling is required owing to the fact that the SAN is the main force contributor. On the economic front, the world and South Africa in particular is still enduring slow economic recovery, implying that the SANDF will for some period still operate in a financially constrained environment. As a consequence, sustainable support is sought for these patrols directly

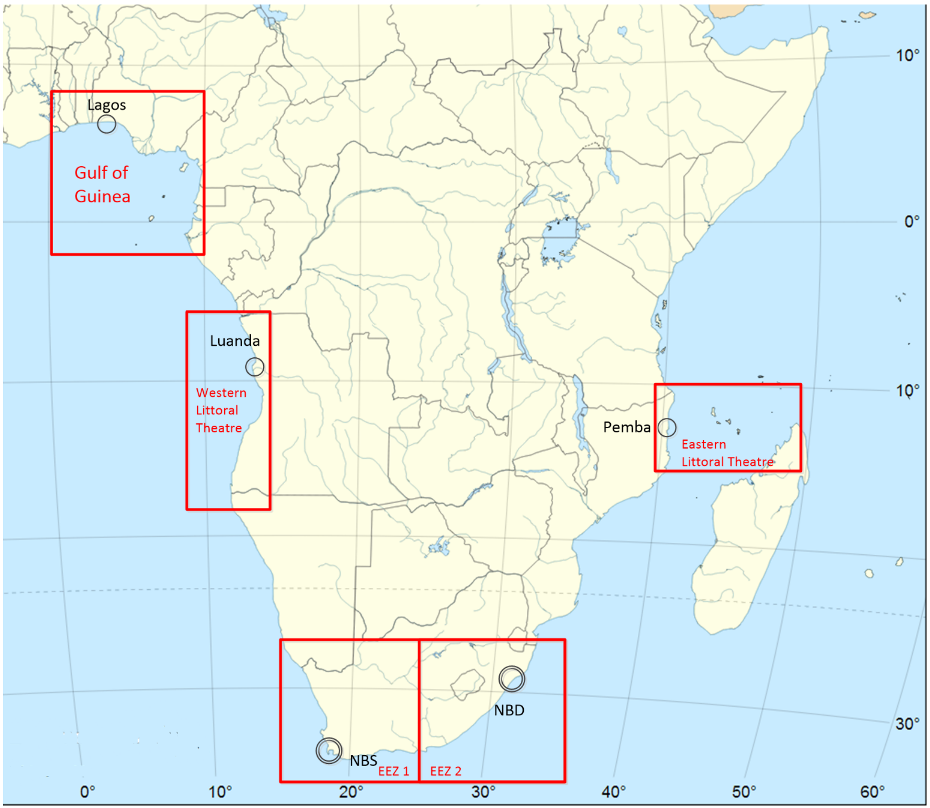


Figure 5.2: Operational Theatres for case study

promoting the reinstatement of Durban as a naval base. The following Flags will indicate continuation in "*Unpaid Vacation Leave*" or a move towards it:

a) Continued or increased piracy related incidents in the Mozambican Channel.

b) No increased effort from Tanzania or Mozambique to acquire adequate patrol capability.

Table 5.3: Data set for Scenario 1.

	Demand			Scenario 1
Affected Areas	**Level 1**	**Level 2**	**Level 3**	**Probability**
EEZ 1	20	10	3	
EEZ 2	20	10	3	27%
ELT	60	15	3	

2. *More Steam*: Scenario 2 is basically a convergence of "Unpaid Vacation Leave" and "The Wild West". In this study "More Steam" also serves as the *worst case* scenario. Criminal activity has established itself on both African coasts, leaving South Africa to split its resources between the WLT and the ELT. South Africa will have to intervene as volatility along the CSR will indirectly affect the cost of maritime trading as ships will evade docking with other countries as they sail along the African coast. Furthermore, the centre of the African economy is shifting north as trading powers no longer see South Africa as the economic key to Africa. Consequently, a popular trade route between Brazil and Nigeria emerges, redirecting critical trade from South Africa. These developments leave the SAN with no options other than to make the Cape Sea Route (CSR) the safest route into Africa, encouraging vessels to make South Africa their first destination. The following Flags will indicate movement towards "*More Steam*":

   a) The flags of both "Unpaid Vacation Leave" and "The Wild West".
   b) The re-emergence of the old Atlantic slave route as a viable Sea Lane of Communication (SLOC) between Brazil and Nigeria.
   c) Continued economic growth of Nigeria and Angola, with the former poised to overtake South Africa as Africa's main economy within the next 20 years, replacing South Africa on the G8 council.

Table 5.4: Data set for Scenario 2.

	Demand			Scenario 2
Affected Areas	**Level 1**	**Level 2**	**Level 3**	**Probability**
WLT	60	15	3	
EEZ 1	20	10	3	23%
EEZ 2	20	10	3	
ELT	60	15	3	

3. *The Wild West*: Scenario 3 sees the SAN tasked with assisting in stabilising the southern regions of the Gulf of Guinea instead of the ELT. The economic expansion of Angola has brought vast infrastructure development to their maritime domain. Unfortunately, this economic boom has exceeded the limits of the country's security capability. Consequently, a potential agreement is initiated, similar to that anchoring Operation Copper, in which the SAN provides patrol support in a operation funded

by SADC or ECOWAS. The following Flags will indicate move towards "*The Wild West*":

a) Angola's GDP growth rate continues above 8 % mark, under this growth it is unlikely that their security capability will keep pace.

b) An increase in criminal activity in the region or a southwards shift of the criminal activity already present in the Gulf of Guinea

Table 5.5: Data set for Scenario 3.

	Demand			**Scenario 3**
Affected Areas	**Level 1**	**Level 2**	**Level 3**	**Probability**
Gulf of Guinea	20	10	3	
WLT	40	10	3	25.3%
EEZ 1	20	10	3	
EEZ 2	20	10	3	

4. *Same Old Oil*: This is a reverted state back to the days before piracy in the Mozambican Channel. Piracy in the ELT is starting to subside due to the unified pressure from regional countries, including France. There are also no signs of potential instability along the western coast of Africa. In this scenario the SAN focuses on its domestic obligations, mainly in the line of Operation Corona. Flags indicating a move towards "*Same Old Oil*":

   a) An overall decrease in pirate activity along both coasts of Africa.

   b) A decrease in political will to continue with Operation Copper.

   c) The failure of BIRO to realise could put extra pressure on the SAN to relinquish regional responsibilities.

Table 5.6: Data set for Scenario 4.

	Demand			**Scenario 4**
Affected Areas	**Level 1**	**Level 2**	**Level 3**	**Probability**
EEZ 1	20	10	3	24.7%
EEZ 2	20	10	3	

5.3.3 Distance Data

Since the model operates in a three-dimensional space, the only true difference between locations are their distances to demand areas. Since facilities are fixed and it is assumed that demand areas, although varying in demand itself, do not migrate, the distance component of this model will remain fixed. The input array takes on a matrix form as presented in Table 5.7 complemented by a graphical illustration (Figure 5.3).

Table 5.7: Distance matrix of demand areas.

	Lagos	**Luanda**	**NBS**	**NBD**	**Pemba**	**Unit**
Lagos	0	1089	2623	3355	4531	nm
Luanda	1089	0	1659	2391	3567	nm
NBS	2623	1659	0	769	1945	nm
NBD	3355	2391	769	0	1186	nm
Pemba	4513	3567	1945	1186	0	nm

Figure 5.3 illustrates distances between areas as the model would interpret them, logically it is impossible for vessels to travel along such lines. The values presented in Table 5.7 are nautical distances from one port to another as would be travelled by a vessel. It is important to double these values when used as inputs as the vessels will need to return to the theatre after scheduled upkeep.

Facilities offering the two higher levels of maintenance will only be sustainable within the borders of South Africa, therefore Naval Base Simon's Town (NBS) and Naval Station Durban (NSD) are the only two facilities capable of providing higher levels of maintenance, albeit the latter after a considerable investment in infrastructure. Therefore the distance matrix should be modified to incorporate this new constraint. The result is graphically illustrated in Figure 5.4, this new matrix includes the assumption that Level 1 service takes place within the operational theatre.

Another valid assumption that should be included into the model is that transit time is not always only spent on transit, sometimes moving through an area serves as an patrol on the way to the destination. An example would be that vessels transiting to the ELT from South Africa compliment operation Corona en route, indirectly taking 304 nm off the transit distance as they are in an operational theatre. Therefore the distance between the ELT and the SAN facilities should be reduced as such (distances in brackets, Table 5.8).

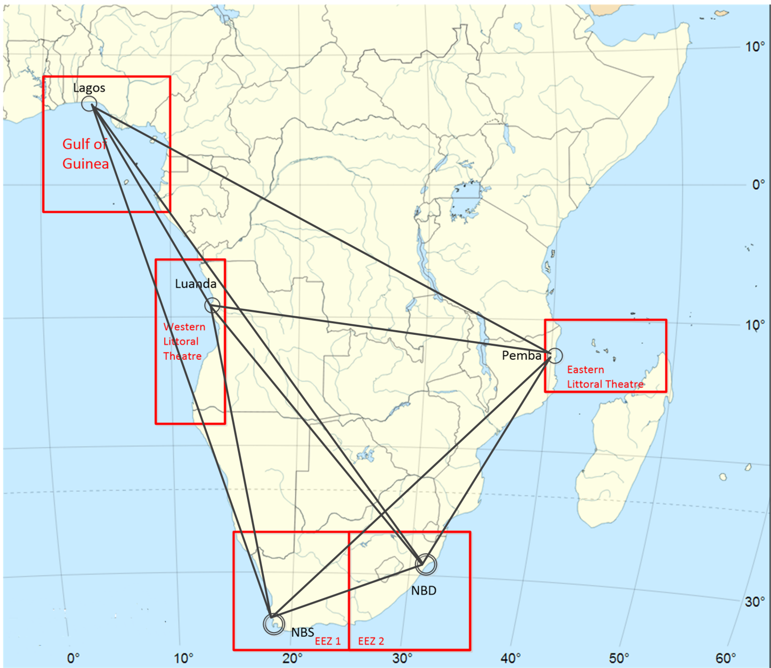


Figure 5.3: Graphical illustration of distance matrix.

The strategic advantage NBD has in respect to providing support for operation Corona should be considered independently.

Table 5.8: Distance matrix modified for patrol en route to demand areas.

	Lagos	**Luanda**	**NBS**	**NBD**	**Pemba**	**Unit**
Lagos	0	1089	2623	3355	4531	nm
Luanda	1089	0	1659	2391	3567	nm
NBS	2623	1659	0	769	(1638)	nm
NBD	3355	2391	769	0	(882)	nm
Pemba	4513	3567	(1638)	(882)	0	nm

5.3.4 Cost Inputs

Cost inputs affect every part of Equation 5.1, which essentially forms the core of the solution formulation. Transit costs are one of, if not the highest, primary expenditures in servicing operational theatres. Hence minimising transit costs will directly increase time spent in the operational theatre. Transit costs c_{ij}

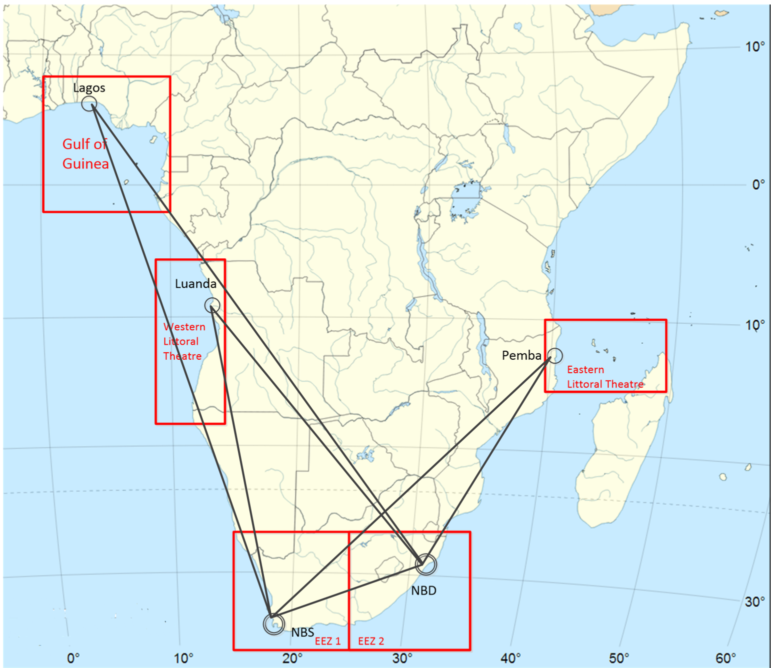


Figure 5.4: Graphical illustration of adjusted distance matrix.

will be the sailing distance divided by the speed z in knots, thus giving hours in transit or at sea. The cost per hour per vessel (x_c), in the case of this study, is assumed to be R790 000 per day sailing (R33 000 per hour). The sailing speed is assumed to be 14 knots in accordance with information mentioned in Section A.3. Given these values, the transit costs can be determined through Equation 5.2.

$$\text{Minimise} \quad \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} \sum_{h=1}^{s} a_{ih}Y_{ijh} + \sum_{j=1}^{n}\sum_{h=1}^{s} F_{jh}Y_{jjh} + V_{jh}\sum_{i=1}^{n} a_{ih}Y_{ijh} \tag{5.1}$$

$$c_{ij} = \frac{d_{ij}x_c}{z} \tag{5.2}$$

The formulation (Equation 5.1) consists of two parts, namely the total transit costs (Equation 5.3) and the total facility costs (Equation 5.4). These variables F and V are the fixed cost of building or expanding a facility of type h and the operating cost of facility of type h respectively, in an area j.

$$TC = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} \sum_{h=1}^{s} a_{ih}Y_{ijh} \tag{5.3}$$

$$FC = \sum_{j=1}^{n}\sum_{h=1}^{s} F_{jh}Y_{jjh} + V_{jh}\sum_{i=1}^{n} a_{ih}Y_{ijh} \tag{5.4}$$

Spesific to this study, the costs of upgrading, expanding or reinstating NBD is taken from an official report by Capt.(SAN) Dooner and Capt.(SAN) Patrick. The cost of upgrading or expanding NBS is derived from a memorandum by Capt.(SAN) Rocher (2010). Operating costs are taken and assumed as the salary cost of the workforce required for each level h facility. The motivation for such assumptions is derived from the concept that the majority of SANDF operating expenditure is employee compensation. As mentioned by Defence minister Mapisa-Nqakula (2013), 55% of the total allocation was spent on the compensation of employees. In the case of the SAN, this could be much higher due to the large amount of outsourcing work by contractors. Other operating costs of any facility will then in fact be negligible compared to the annual salary expense. Table 5.9 presents the fixed and operating values as taken and derived from sources (in brackets) and adjusted to 2014 prices at an interest rate of 5%.

Table 5.9: Fixed and operating costs of h level facilities.

	NBS		NBD		
	F	**V**	**F**	**V**	**Unit**
Level I	N/A	N/A	N/A	N/A	R'000
Level II	N/A	19,969(17,250)	9,660 (9,200)	34,844(33,185)	R'000
Level III	N/A	52,382(45,250)	25,021 (23,830)	65,053(61,955)	R'000

Since Level One support consists of maintenance provided in the SMP, which takes place on the vessel when birthed, no noteworthy investment is necessary when a berthing opportunity is available. This applies to NBS, NBD or any other Level One support facility used while operating in a theatre. Therefore the fixed and operating costs associated with Level One facilities are assumed not to be applicable. This assumption additionally serves as a simplification of the input data. Since NBS already operates the facilities necessary to provide full 3rd and 4th line support facilities, no additional capital investment would be required.

The preventative maintenance required, in terms of man-hours, is assumed to be 80 000 per annum for BIRO vessels. From a memorandum by Capt.(SAN) Rocher (2010) it is clear that Dockyard in NBS would technically have the extra capacity for such man-hours if vacant posts were staffed in both FMU and Dockyard. He states that 150 000 man-hours approximately equals R35 million in labour cost. Capt.(SAN) Rocher further recommends that FMU capability should increase by 75 000 man-hours (R17 250 million) and that Dockyard has a shortfall of 120 000 man hours, which according to the same calculation translates into R28 million for labour expenses. Combining the needed FMU and Dockyard cost for sustained upkeep capability if BIRO vessels were to be served at NBS results in R45 250 million. This expense includes staffing post necessary to effectively service other vessels and submarines to free up capacity for BIRO vessels.

In the case of NBD, the fixed cost of improving the technical support by servicing existing equipment relates to R9.2 million (Capt.(SAN) Dooner and Capt.(SAN) Patrick, 2012, A-12). This includes the repair and upgrade of the syncrolift. The reason why the marine lift is included in the cost is that it could be used to provide 3rd line support for the IPV component of BIRO amongst other things. The R23 830 found in Table 5.9 is derived from the most complete costing done in the Capt.(SAN) Dooner and Capt.(SAN) Patrick report. This total includes relocation, accommodation, upgrading, replenishing and improvement costs. The R9.2 million needed to improve technical support is also included in this cost. Specialist equipment needed for BIRO vessels are excluded from the table as their cost is unknown at the time of writing. However, this cost will be generic, irrelevant of where the equipment will eventually be located. The operating costs of level h facilities in NBD are taken from a cost comparison table, providing the total cost of salaries for a fully staffed FMU and 3rd Line capability at Durban.

5.3.5 Assumptions and limitations

The model operates under certain assumptions, be they of a functional nature or purely about input behaviour. These assumptions need to be recognised in order to place the model in proper context. Consequently, the following modified assumptions from the Calvo and Marks (1973) formulation also holds for this model, classified in categories pertaining specifically to the Model, Inputs and Costs.

1. *Model:*

   a) The main assumption of the model is that it minimises cost of preventative maintenance, corrective maintenance is not included in the model.

   b) The assignments in the proposed model are complete, no partial assignments are allowed. That is service demand h, in theatre i, is completely assigned to a h-type facility, permitting no future variation.

c) There is no referal to a higher level facility after initial assignment, meaning a ship on a routine second line berthing, receiving FMU support, will not be referred to a third line facility if some unforeseen problem is detected. This limitation is not compatible with the dynamics of the real-world situation. This limitation is acceptable as corrective repairs are the exception to the rule.

d) Since the distances are not scenario-dependent, c_{ijk} and Y_{ijhk} is replaced by c_{ij} and Y_{ijh} throughout the formulation, thereby significantly reducing the number of decision variables (Daskin *et al.*, 1997, 235).

e) Vessels go to the closest appropriate facility of type h for level h maintenance.

f) Patrol vessels are more economically sustainable than larger war ships and will thus be considered for sustained patrols in Gulf of Guinea.

g) All facilities offer lower level maintenance.

h) All maintenance levels are alike, irrelevant of the facility.

2. *Inputs:*

a) The demand a_{ih} in theatres are presented deterministically although they are considered stochastic by the model through the scenario approach.

b) Demand a_{ih} is independent of piracy incidents, it is coupled to the type and number of ships operating in the specified theatre, which is indirectly influenced by piracy incidents.

c) Movement or creation of new demand theatres are not considered. For example, if piracy should escalate north of the ELT and consequently justifies the SAN operating more to the north, the ELT will not be able to move nor will a new theatre be created.

d) The distance is fixed between theatres and taken as the distance between the main harbours in each theatre.

e) It is assumed that the economic transit speed of the vessel will be between 10 and 14 knots, taken from Section A.3

3. *Costs:*

a) The operating cost of a BIRO OPV is R790 000 per day sailing, derived from the operating cost of Sarah Baartman environmental protection OPV.

5.4 Results

The data presented in the previous sections were applied to the model formulation using Lingo, an Optimisation Modelling Program for Linear, Non-linear, and Integer Programming.

5.4.1 Short Term Results (5 Years)

The first run of the model simulated 5 years of planned maintenance demand and the corresponding costs. The operational cost input was the sum of 5 years of salaries increased by inflation each year (Table 5.10). No other increase in costs was incorporated, assuming all other costs were subject to inflation and, as they are eventually compared to each other, would negate any increases experienced. Combined with the fact that the fixed and operating costs are approximations, any increase out of sync with inflation would be trivial among the other inaccuracies used as input. The objective of this model is to determine the optimal hierarchical facility network between location options that are assumed to be similarly influenced by externalities. The effect of different inflation rates for geographies and services are neglected since higher level facilities can only be considered within South Africa and are therefore only exposed to local influences. The cost per hour sailing was adjusted for inflation and averaged over the 5 year period, amounting to a average of R38,292 per hour spent in transit.

Table 5.10: Total operating costs of h level facilities.

	NBS	**NBD**	**Unit**
Level II	110,341	192,536	R'000
Level III	289,446	359,457	R'000

The following results were obtained.

Table 5.11: Case study facility location results.

Facility Type	**Area**
I	Operational Theatre
II	NBS
III	NBS

The objective function for a 5 year simulation amounts to R158.786 million. This might seem odd as the operating cost of having a Level 3 facility at SMST is R289.446 million and according to the model there should be one. The reason for this discrepancy can be attributed to the weighing of the scenarios, each having a probability value in the vicinity of 25%. In effect, the objective total has been divided by four, where in reality it should be in the area of R635.139 million. Table 5.11 presents the facility location results whilst Table 5.12 lists the theatre assignment results.

Table 5.12: Case study assignment results.

Area	Group	to Facility
Gulf of Guinea	II	NBS
Gulf of Guinea	III	NBS
WLT	II	NBS
WLT	III	NBS
EEZ1	II	NBS
EEZ1	III	NBS
EEZ2	II	NBS
EEZ2	III	NBS
ELT	II	NBS
ELT	III	NBS

The simplicity of the model allowed it to be run with a Level 3 facility forced at NBD to compare the costs of the only two options permitted by the case study. With the added constraint, the objective function reached R211.611 million, approximating to R846.448 million in total. Therefore it is logical to conclude that over the course of the next 5 years, considering the four possible scenarios and their probabilities, the facility locations and assignments presented in Tables 5.11 and 5.12 reflect the optimal solution obtained.

5.4.2 Medium Term Results (15 Years)

The second run of the model simulated 15 years of planned maintenance demand and the corresponding costs. The operational cost input was the sum of 15 years worth of salaries increased by inflation each year (Table 5.13). As with the 5 year simulation, no other increase in costs was incorporated assuming all other costs were subject to inflation and, as they are eventually compared to each other, would negate any increases experienced. Once again, combined with the fact that the fixed and operating costs are approximations, any increase out of sync with inflation would be trivial among the other inaccuracies used as input. The cost per hour sailing amounted to a 15 year average of R49 846.

Since the first execution of the model over a 5 year period proved that the operating costs were the major cost drivers, there is no clear reason to run the model over a 15 year period as the operating costs of NBD will never be less than those of NBS, concluding that capital investment at NBD is unlikely to be considered as it does not unlock a cheaper option. Therefore the optimal solution is unlikely to change from the 5 year execution.

The objective of this specific simulation is to determine the cost difference between the two options as in the previous execution to determine the cost to company for the perceived added benefits of opening a Level 3 facility in Durban. The following results were obtained.

Table 5.13: Total operating costs of h level facilities for 15 years.

	NBS	**NBD**	**Unit**
Level II	541,244	944,425	R'000
Level III	1,419,786	1,763,202	R'000

The following results were obtained.

Table 5.14: Case study facility location results.

Facility Type	**Area**
I	Operational Theatre
II	NBS
III	NBS

The objective function for the 15 year simulation amounts to R470.575 million, which in reality should be approximately R1.882 billion. Table 5.14 presents the facility location results whilst Table 5.15 lists the theatre assignment results. As expected, these locations and assignments are similar to the optimal results of the 5 year simulation.

Repeating the previous process, the model was run with a Level 3 facility forced at NBD to compare the costs of the only two options permitted

Table 5.15: Case study assignment results.

Area	Group	to Facility
Gulf of Guinea	II	NBS
Gulf of Guinea	III	NBS
WLT	II	NBS
WLT	III	NBS
EEZ1	II	NBS
EEZ1	III	NBS
EEZ2	II	NBS
EEZ2	III	NBS
ELT	II	NBS
ELT	III	NBS

by the case study. With the added constraint, the objective function reached R600.521 million, approximating to R2.402 billion in total. Therefore it is conclusive that over the course of the next 15 years, considering the four possible scenarios and their probabilities, the facility locations and assignments presented in Tables 5.14 and 5.15 reflect the optimal solution obtained.

5.5 Analysis

From an analytic perspective the question has always been a simple one, does the transit costs saved justify the investment and operating costs of a facility closer to the operational theatres? An analysis of the results will highlight the sensitivity of the input parameters and put the results in perspective relative to each other.

5.5.1 Applicability

From the start, the research objective intended to solve the optimal pattern of multi-level maintenance facilities for the SAN. This particular research problem is rooted in the escalation of piracy and a consequential requirement for additional patrol vessels. The model developed in this thesis sets out to solve such a research problem but remains specific to the preventative maintenance of the new patrol vessels. Therefore the model does not incorporate the patterns and maintenance schedules of any other vessels. The motivation behind such an omission, except for reducing model complexity, stems from the assumption that the SAN would have optimised their maintenance pattern for their current fleet requirements when they acquired the new frigates and submarines. If the optimal solution included a fully operational base at Durban, then it would have been kept at that state or reinstated without the requirement brought on by project BIRO.

5.5.2 Sensitivity Analysis

In this section the inputs will be tweaked to determine the limits of the parameters within which the model prefers the current optimal solution. These parameters include the cost per hour sailing, the transit speed of the vessel, theatre demand as well as the scenario probabilities. Initially, for analytical reasons, only Scenario 1 will be activated in the model, the reason being that the optimal solution for Scenario 1 alone prefers Level 3 and Level 2 facilities in SMST while it is the only scenario that should be advantaged by a fully operational support base in Durban. The model justifies Level 3 and Level 2 facilities in Durban under the following respective conditions, over a 5 year period, whilst only considering Scenario 1:

Table 5.16: Model parameter limits.

Parameter	Value	Unit
Transit Speed	< 9.996	knots
Cost per hour sailing	$> 53\,641$	R
Capital invested in SMST	$> 29\,957$	R,000
Additional Operational costs SMST	$> 29\,957$	R,000
Demand in ELT	> 29	-

From Table 5.16 it becomes clear that the perceived distance advantage is not that relevant, only if ships spend more than 3.2 days at sea transiting between NBD and NBS will a base at Durban offer any economical advantage. In the same breath, should the costs of operating any new vessel be above R53 641 per hour sailing (R1.287 million per day) it would justify a support facility in Durban. From a financial perspective, only a capital investment or operational increase of more that R29.957 million over the next 5 years with regards to NBS, purely for the purpose of accommodating the new vessels, would justify full 3rd Line capability in NBD.

The last parameter value that would justify a support facility in Durban would be a dramatic increase in demand, to such an extent that ships would need to travel from the ELT roughly 29 times for 2nd and 3rd Line maintenance. Such demand will only be required by 2 vessels on simultaneous, continuous patrol in the ELT, a number unwarranted for any situation except maybe war.

Another deduction that can be made from the table is the similarity of the parameter limits with other vessels in the service of the SAN. To name two examples, the lower speed limit of 10 knots is above the transit/submerged speed of a Type 209 submarine. The cost per hour of such a vessel will undoubtedly exceed R38 292 per hour sailing, ensuing that transit is extremely expensive for submarines. A capable support facility in Durban could then be beneficial to submarines. The sailing cost of R 53 641 per hour is characteristic of the sailing costs of a frigate, therefore it can be argued that a new vessel similar to the current frigate might justify the utilisation of a support facility at Durban.

To conclude, the application of the developed formulation to the case study produced the *most efficient solution*, not necessarily the *preferred solution*. Therefore these results should be considered with other inputs in an external decision process to produce a preferred location, although it might not be optimal from a cost perspective.

5.6 Chapter Summary

Chapter 5 employs the previously developed facility location model to a suitable and relevant problem within the context of the research objectives. In essence, the chapter applies the formulation to determine if the SAN should reinstate one of their scaled-down naval bases to accommodate a new type of multi-role patrol vessel. At the outset of the chapter a more in-depth introduction is given to better contextualise the case study. Thereafter the operational and maintenance doctrine of the SAN is elaborated upon, defining Navy specific definitions and maintenance terminology as well as the principals of Upkeep and Usage Plans.

The maintenance network of the SAN revolves around a core scheduling system, called usage and upkeep plans, which determines the scheduled preventative maintenance frequency and duration for each type of vessel. It is from this 5 year programme that the upkeep demand of the new type of vessel is derived. The end result was an approximation that each vessel will need to "visit" a Level 3 (3^{rd} and 4^{th} line maintenance) facility at least three times per 5 year cycle and between 10 to 15 times for FMU (Level 2) support.

Section 5.3 clarifies and motivates the data inputs of the model, subsequently the demand areas are defined and the scenarios presented, along with the distance and cost data. The data sets derived from each scenario, and validated in Chapter 6, is presented in tabular form for each scenario. The scenarios, portraying possible future realisations for the SAN, were crafted by following a Game Board model developed by Clem Sunter and Chantell Ilbury. The Game Board presents four scenarios, each bordering two driver axes, namely distance and demand as illustrated in Figure 5.5.

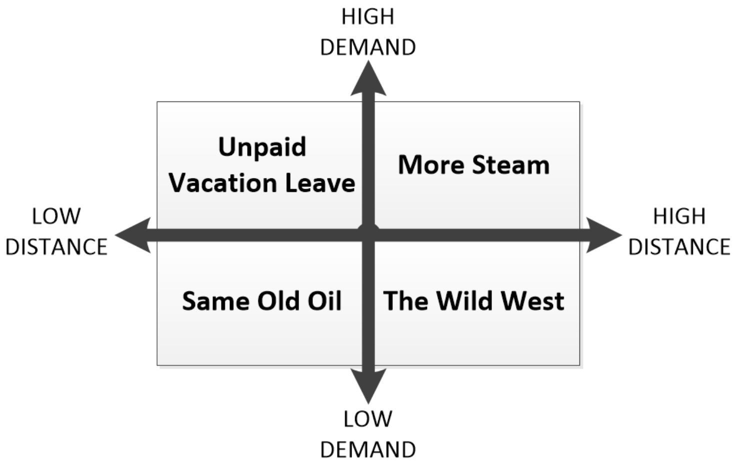


Figure 5.5: Case study Game-Board

A brief summary of each scenario will be needed to fully understand the figure:

1. The first scenario, *Unpaid Vacation Leave*, portrays the current state of the SAN; domestic responsibilities coupled with piracy patrols in the Eastern Littoral Theatre (ELT), namely the Mozambican Channel. The regional responsibilities so close to home places Scenario 1 in the low distance: high demand quadrant.

2. Scenario 2, *More Steam* (high distance:high demand), serves as the Worst Case Scenario for the input array. It sketches regional responsibilities on both the east and west coast of Africa.

3. *The Wild West*, or Scenario 3, places future SAN activity up the west coast of Africa, even requiring patrols in the Gulf of Guinea. Since the majority of the involvement will be in the form of training or consulting, the scenario is placed in the high distance: Low Demand Quadrant.

4. The final scenario, *Same Old Oil*, is a reverted state back to the before piracy in the Mozambican Channel. In this scenario the SAN focusses on its domestic obligations, mainly in the line of Operation Corona.

The case study was facilitated by reports providing the needed cost inputs, or at least provided a point of reference to adjust recent costs for inflation until they were relevant. Thereafter the assumptions and limitations, more relevant to the case study, are discussed to provide context to the results.

The second last section provides the results of the case study. A 5 and 15 year dataset was used as input to obtain comparable results. The optimal solution in both cases were to locate Level 3 and Level 2 facilities in NBS, whilst Level 1 facilities should be provided in the operational theatre (Table 5.17). Since the support capability in NBS already exist, the results conclude that no decision to reinstate NBD should be taken at this time.

The following results were obtained.

Table 5.17: Case study facility location results.

Facility Type	Area
I	Operational Theatre
II	NBS
III	NBS

In order to analyse the results, the last section was divided into two parts, one to comment on the applicability of the results and the second to comment on the sensitivity of the input parameters. The model developed in this thesis and applied in this chapter, remains specific to preventative maintenance of new, not yet acquired patrol vessels. Therefore the model does not incorporate the sailing patterns and maintenance schedules of other vessels. This omission stems from the assumption that the reinstatement of NBD was not considered as part of the optimum upkeep network for the current vessels and submarines, otherwise it would have been kept as a base or would have been reinstated without the requirement brought about by project BIRO.

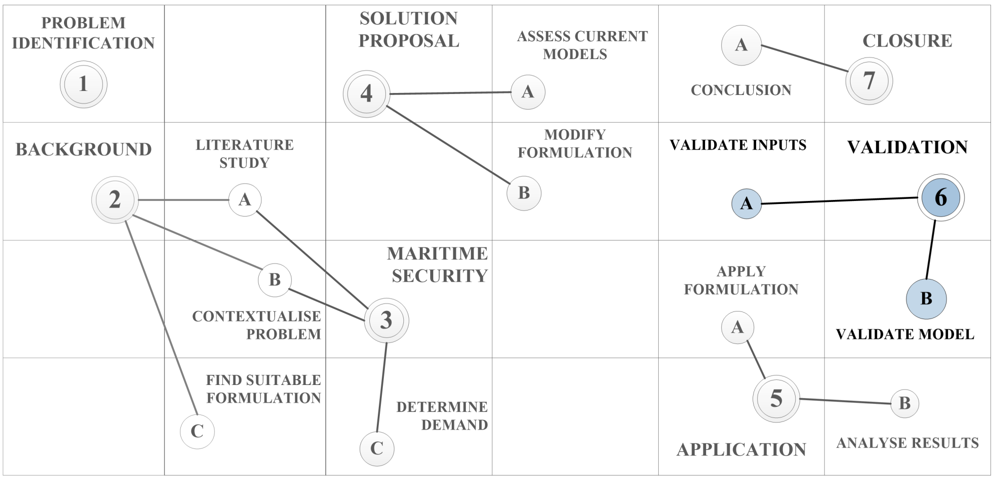
Analysis of the parameters shows that the reinstatement of NBD would be more beneficial to submarines, due to their slow transit speed, and frigates, due to their high cost per hour sailing. Other financial factors that would justify a Level 3 support facility in Durban consist of a R29.957 million investment requirement or operational cost increase in NBS to accommodate only the BIRO vessels. The last parameter value that would justify a support facility in Durban is a dramatic increase in demand equal to 2 vessels on simultaneous, continuous patrol in the ELT, a number unwarranted for any situation except maybe war. These parameter will only be applicable if the SAN is 100% sure it will only operate in the ELT for the next 15 years.

Chapter 6

Model Validation

Chapter Aim:

The primary purpose of this section is to validate the model. The secondary objective is to have experts confirm the inputs of the optimisation model, namely demand areas and the subsequent scenarios. This process aims to highlight inadequacies in the assumptions and test the response of organisational leaders.



Chapter Outcomes:

- Summary and analysis of expert input.
- Confirmation of demand areas.
- Validation of input scenarios.
- Confidence in model and results.

6.1 Validation

Chapter 6 consists of two parts, the first validating the inputs of the model, the second part validating the model itself. Although this chapter follows on Chapter 5 in the layout of this thesis, in reality it should be seen as an adjacent chapter as illustrated in Figure 6.1. In other words, the validated data is fed to the application of the model whilst the results are used to validate the model itself.

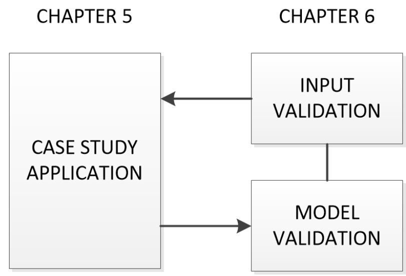


Figure 6.1: Illustrated interaction between Chapter 5 and Chapter 6.

Classic validation offers three ways in which the model inputs and the model itself can be validated:

1. Interviews with experts;
2. Implementation; and
3. Model case studies.

There are advantages and disadvantages to each of these forms. Each will be discussed briefly.

6.1.1 Interviews

The interviewer would thus, in the case of validating the demand areas and scenarios, look to obtain knowledge from the interviewee, which will either refute or confirm the proposed demand areas. There are four main interviewing types (Mouton, 2008):

1. Structured self-administered questionnaires;
2. Structured telephone interviewing;
3. Semi-structured focus group interviewing; and
4. Free attitude interviewing methods.

Throughout the research process it became evident that literature explicitly concerning future and present demand areas in the South African context were found somewhat lacking. Therefore the research conducted called for experts to express their opinion on demand areas deducted from the inadequate literacy.

6.1.2 Implementation

The implementation of the model in an organisation like the SAN purely for the purpose of validation is not possible due to the immense financial and strategic implications of the results. Irrespectively, the advantages are obvious, from actual results to be seen to the adoption thereof by the decision makers. The disadvantages however, are that this method is not suitable for the length of study as permitted by the degree Master of Science in Industrial Engineering. The amount of time needed to practically test the results of the framework could range from one day to at least five years, as strategy analysis takes time.

6.1.3 Model Case Studies

The validation of the research through the use of a model case study would produce results, albeit most likely inconclusive. Furthermore, the model can be applied to certain old case studies but, as the research problem is too specific, it would have to be somewhere in the domain of the original construction of NBD combined with similar demand theatres. Such a case study environment is highly unlikely and therefore not considered within the scope of this thesis.

6.1.4 Summary

A structured self-administered questionnaire was issued to experts (deputy director level and above) to not only obtain their opinion on the presented material but to gain extra input on the subject of which they are subject matter experts. The participants were introduced to the questionnaire via an interview. Thereafter they were left to complete it in their own time. The drawback is that the interviewee could only interpret the problem with the knowledge he/she is dealt with and what was presented to them.

6.2 Questionnaire Analysis

The selected interview method was in the form of a data questionnaire to experts in the technical, logistical and combat fields of the SAN. The interviewees were presented with the questionnaire found in Appendix B, which provided space for additional input and opinion at the end of each section. The questionnaire was issued to specific experts as not to pollute the data. Hard copies of the questionnaires were issued to the participants and collected after completion. An example of a completed questionnaire can be found in Section B.3.

Objectives were set to extract the interviewee's expert opinion and recommendations on the applicability of the assumed demand areas and relevant scenarios. The five objectives and their reason for existence follow:

1. *Validate potential future demand theatres.* This objective is preliminary and actually secondary to the next one as the assumed theatres of operation in the scenarios need to be motivated and justified. The validation of potential future demand areas will fix the distance component of the input array.

2. *Validate potential future scenarios.* The optimisation formulation attempts to minimise cost across a set of scenarios. Each scenario consists of three components; distance through activation of relevant demand theatres, demand through activation of numerous demand theatres and validation of the proposed combination of distance and demand.

3. *Provide input probabilities of scenarios realising.* In conjunction with the validation of the scenarios, the interviewee is requested to input a probability of the scenario realising.

4. *Validate proposed location criteria.* To complement and contribute to the research on facility location, a set of location criteria specific to naval base location is presented to the interviewees to refute or confirm.

5. *Rank location criteria in scale of importance.* To complement the previous objective and provide deeper insight into the mindset of naval planners, the interviewees were requested to rank the main categories.

6.2.1 Interviewees

Seven interviewees were identified in their respective fields within the SAN, namely three in technical, two in logistics or support and two in combat. The seven interviewees, their current or last rank held, current or last positions held and years of service are listed in Table 6.1 according to seniority.

6.3 Input Validation

As mentioned, the data collection method was in the form of a data questionnaire handed to experts in the technical, logistical and combat fields of the SAN. The interviewees were presented with the questionnaire found in Appendix B, which provided space for additional input and opinion at the end of

Table 6.1: List of experts interviewed.

Interviewee	Rank	Post	Exp
Officer A	R Adm.(JG)	Chief of Fleet staff	36
Officer B	Capt.(SAN)(Ret)	Mngr System Support	45
Officer C	Capt.(SAN)(Ret)	SSO Commodities (DFL)	40
Officer D	Capt.(SAN)	OC SA Naval College	34
Officer E	Capt.(SAN)	Senior Officer SU Warfare	30
Officer F	Capt.(SAN)	Platform manager NES	19
Officer G	Commander	Platform manager NES	15

each section. The questionnaire was issued to specific experts as not to pollute the data.

The questionnaire's primary objective was to gain endorsement for the model's scenario inputs, compromising of demand areas which need secondary confirmation. Input was acquired in the form of indicating a level of agreement, on a scale from 0 to 3, on a provided table. 0 indicating a strong disagreement; 1 citing disagreement; 2 indicating agreement and 3 conveying strong agreement. N/A can be ticked if the reader finds he is unprepared to provide input at the time. An example is provided below for validating the demand areas in which the reader disagrees with the *Gulf of Guinea* being a potential demand area:

	Level of Agreement				
	N/A	**0**	**1**	**2**	**3**
Gulf of Guinea			X		

Collecting input for the scenarios worked in a similar method, except for the addition of a probability input. An example is provided below for validating the scenarios in which the reader strongly agrees with the scenario and the flags, subsequently he/she assigns a probability of 40%[1] to it:

Fuzzy logic was used to construct a look-up table for values to derive average and mean values from Table 6.2, and as shown in Figure 6.2.

[1]The probabilities are of the scenarios realising as of present and have to accumulate to 100 %, with the present scenario having the highest probability. Please see Section B.2 for a clearer explanation

	Level of Agreement					Scenario 1 Probability
	N/A	0	1	2	3	
Scenario 1					X	40 %
Flags					X	

Table 6.2: Linguistic value look-up table

Fuzzy language	**Meaning**
Strong Agreement	1
Agreement	0.75
Disagreement	0.25
Strong Disagreement	0

6.3.1 Demand Areas

The endorsement of demand area input is preliminary and actually secondary to the confirmation of the scenarios. The reason being, the assumed theatres of operation in the scenarios need to be motivated and justified. The validation of potential future demand areas will fix the distance component of the input array.

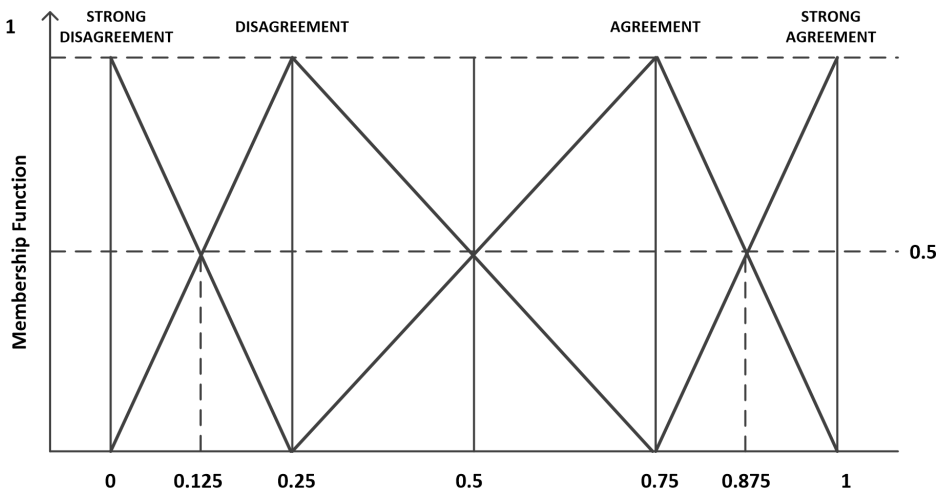


Figure 6.2: Membership functions of linguistic values for criteria ratings.

1. *Gulf of Guinea:* The data collected shows more than a general agreement with this specific demand area as a future area of interest for the SAN. Analysis shows an average of 0.857 with a membership function of 0.56 (Figure 6.2). Simply put, roughly half the experts agree strongly while the rest merely agree. The most popular input from the experts was 0.75, once again indicating agreement. Therefore the *Gulf of Guinea* demand theatre qualifies for consideration in the scenario phase.

   <u>Notable feedback</u>:
   The Gulf of Guinea of will only be of an intelligence interest to the SAN to identify threat trends, but "the SAN could operate in support of UN or regional organisations."

2. *Western Littoral Theatre (WLT):* The data collected shows a general agreement with this specific demand area as a future area of interest for the SAN. Analysis shows an average of 0.75 with a membership function of 1, indicating a strong majority of agreement. Therefore the *WLT* demand theatre qualifies for consideration in the scenario phase.

   <u>Notable feedback</u>:
   It was noted by more than one expert that the SAN would most likely operate in support of SADC security in terms of patrols, training and to prevent possible threat migration south.

3. *Namibian Fishing Zones:* The data collected shows a general disagreement with this demand area, analysis shows an average of 0.46 with a membership function of 0.56 and a majority citing of disagreements. Therefore the *Namibian Fishing Zones* theatre does not qualify as an input in the scenario phase.

   <u>Notable feedback</u>:
   It was noted that the SAN may be required to assist Namibia in maritime security operations but not likely in the "Fishery Protection Role".

4. *South Africa's Economic Exclusive Zone (EEZ):* All of the experts strongly agreed that local patrols will be part of future SAN obligations. In consequence, the demand theatre *South Africa's EEZ* qualifies as an input for the scenario phase.

5. *Eastern Littoral Theatre (ELT):* The majority of the experts interviewed strongly agreed that regional patrols to the east, namely in the ELT, will be part of future SAN obligations. Data collected shows an average of 0.93 and a membership function of 0.68. In consequence, the demand

theatre *ELT* qualifies as an input the scenario phase.

6. *The Strait of Hormuz:* The data collected shows a undecided outcome with this demand area, analysis shows a average of 0.5 with a majority citing of general disagreements. The bulk of disagreements combined with some notable feedback endorses that the *Strait of Hormuz* theatre should not be included in the scenario phase.

   Notable feedback:
   It was mentioned that the SAN would find it very difficult to conduct sustained operations over a long period north of Tanzania.

   One expert noted that the shutting of the Strait of Hormuz and the possible closure of the Suez Canal as a result will serve to increase the importance of the CSR, hence the strategic significance of South Africa and NBS, but will not necessarily substantiate direct involvement.

It is evident that two of the six demand areas are not, in the opinion of experts, possible future areas of operation for the SAN. These two areas are the Namibian Fishing Zones and the Strait of Hormuz, although the latter could have a significant impact on the domestic maritime security of South Africa as stated by Rear Adm.(JG) Jameson.

6.3.2 Scenario 1: Unpaid Vacation Leave

The first scenario is based on the assumption that piracy continues to be a threat in the Mozambican Channel for the next 10 -15 years. This persistence will motivate a need for increased patrol capability, contributing to the motivation for "Project BIRO". This scenario is placed in the high demand quadrant as continuous patrol is required owing to the fact that the SAN is the main force contributor. On the economic front, the world and South Africa in particular is still enduring slow economic recovery, implying that the SANDF will for some period still operate in a financially constrained environment. As a consequence, sustainable support is sought for these patrols directly promoting the reinstatement of Durban as a naval base. The following flags will indicate continuation in "*Unpaid Vacation Leave*" or a move towards it:

1. Continued or increased piracy related incidents in the Mozambican Channel.
2. No increased effort from Tanzania or Mozambique to acquire adequate patrol capability.

Discussion and Confirmation:

Table 6.3: Scenario 1 validation summary.

Interviewee	Scenario	Flags	Probability
Average	0.75	0.71	27 %
Popular	0.75	1	30/40 %
μ	1	0.9	

The average expert opinion of this scenario is 0.75 with a membership function of 1, citing basic agreement (Figure 6.2). For the flags the experts have responded with agreement as a flag average of 0.71 was calculated with a membership function of 0.9. The averaged probability for the scenario realising is 27%. Agreement with this scenario was expected as it reflects a familiar situation, one the SAN currently finds itself in. The flags have also been validated, meaning they could be used as legitimate indicators for movement towards or away from scenario 1. In conclusion, Scenario 1 qualifies as an input to the model.

Feedback on Scenario 1 notes that global piracy is expected to decrease within the next 5 to 10 years. A decrease in criminal activity is expected to follow within the next 10 to 15 years. Therefore it is already evident that movement is taking place away from *Unpaid Vacation Leave*.

6.3.3 Scenario 2: More Steam

Scenario 2 is basically a convergence of "Unpaid Vacation Leave" and "The Wild West". In this study "More Steam" also serves as the *worst case* scenario. Criminal activity has established itself on both African coasts, leaving South Africa to split its resources between the WLT and the ELT. South Africa will have to intervene as volatility along the CSR will indirectly affect the cost of maritime trading as ships will evade docking with other countries as they sail along the African coast. Furthermore, the centre of the African economy is shifting north as trading powers no longer see South Africa as the economic key to Africa. Consequently, a popular trade route between Brazil and Nigeria emerges, redirecting critical trade from South Africa. These developments leave the SAN with no options other than to make the Cape Sea Route (CSR) the safest route into Africa, encouraging vessels to make South Africa their first destination. The following Flags will indicate movement towards "*More Steam*":

1. The flags of both "*Unpaid Vacation Leave*" and "*The Wild West*".
2. The re-emergence of the a viable Sea Lane of Communication (SLOC) between Brazil and Nigeria, opening direct trade between South America and Africa.
3. Continued economic growth of Nigeria and Angola, with the former poised to overtake South Africa as Africa's main economy within the next 20 years, replacing South Africa on the G8 council.

Discussion and Confirmation:

Table 6.4: Scenario 2 validation summary.

Interviewee	Scenario	Flags	Probability
Average	0.57	0.54	23 %
Popular	0.75/0.25	0.75	20 %
$\boldsymbol{\mu}$	0.62	0.55	

The average expert opinion of this scenario is 0.57 with a membership function of 0.62, citing a little bit more agreement than disagreement (Figure 6.2). Further analysis shows that three experts disagree with the scenario, three agree with the scenario and one expert strongly agrees with "*More Steam*" as a possible future scenario for the SAN. For the flags the experts have responded with majority in agreement and a flag average of 0.54 was calculated with a membership function of 0.55. The averaged probability for the scenario realising is 23%. Although the average agreement for this scenario is not ideal, it has a majority of agreements and therefore at least has to be considered in the model. The probability input serves as a counterbalancing mechanism, meaning if experts do not agree with the scenario, their probability input should reflect their opinion of the likelihood of it realising. Considering the arguments mentioned, it seems that this scenario should be included in the model.

Feedback on "*More Steam*" notes that economic cooperation between Brazil/ USA and Angola very likely via a new SLOC. To ensure continued cooperation with Namibia and Angola and to negate Brazilian influence will be more of a reason to assist in the WLT than to counter criminal activity.

6.3.4 Scenario 3: Wild West

Scenario 3 sees the SAN tasked with assisting in stabilising the southern regions of the Gulf of Guinea instead of the ELT. The economic expansion of Angola has brought vast infrastructure development to their maritime domain. Unfortunately, this economic boom has exceeded the limits of the country's security capability. Consequently, a potential agreement is initiated, similar to that anchoring Operation Copper, in which the SAN provides patrol support in a operation funded by SADC or ECOWAS. The following Flags will indicate movement towards "*The Wild West*":

1. Angola's GDP growth rate continues above 8 % mark, under this growth mark it is unlikely that their security capability will keep pace.
2. An increase in criminal activity in the region or a southwards shift of the criminal activity already present in the Gulf of Guinea

Discussion and Confirmation:

Table 6.5: Scenario 3 validation summary.

Interviewee	Scenario	Flags	Probability
Average	0.68	0.61	25.3 %
Popular	0.75	0.75	30 %
$\boldsymbol{\mu}$	0.83	0.69	

The average expert opinion of Scenario 3, "*Wild West*", is 0.68 with a membership function of 0.83, citing an average very close to basic agreement (Figure 6.2). For the flags the experts have responded with majority in agreement and a flag average of 0.61 was calculated with a membership function of 0.75. The averaged probability for the scenario realising is 25.3%. Although the average agreement for this scenario is not ideal it has an average very close to basic agreement, with two experts strongly agreeing that Scenario 3 is a possible future realisation for the SAN. Consequently, Scenario 3 qualifies as a valid input for the model.

Feedback on "*Wild West*" notes that Angola is more capable to increase its maritime capability than Mozambique or Tanzania.

6.3.5 Scenario 4: Same Old Oil

"*Same Old Oil*" is a reverted state back to the days before piracy in the Mozambican Channel. Piracy in the ELT is starting to subside due to the unified pressure from regional countries, including France. There are also no signs of potential instability along the western coast of Africa. In this scenario the SAN focuses on its domestic obligations, mainly in the line of Operation Corona. Flags indicating a move towards "*Same Old Oil*":

1. An overall decrease in pirate activity along both coasts of Africa.
2. A decrease in political will to continue with Operation Copper.
3. The failure of BIRO to realise could put extra pressure on the SAN to relinquish regional responsibilities.

Discussion and Confirmation:

Table 6.6: Scenario 4 validation summary.

Interviewee	Scenario	Flags	Probability
Average	0.61	0.79	24.7 %
Popular	0.75	1/0.75	10/25 %
$\boldsymbol{\mu}$	0.69	0.84	

The average expert opinion for Scenario 4 is calculated to 0.61 with a membership function of 0.69, citing a average somewhat in the middle of agreement and indecision (Figure 6.2). For the flags the experts have responded with a majority of basic and strong agreements, resulting in a flag average of 0.79 and a membership function of 0.84. The averaged probability for the scenario realising is 24.7%. As in the case of scenario 2, *More Steam*, the average agreement for this scenario is not ideal but it has four of the experts agreeing and one strongly agreeing. Therefore, Scenario 4 also qualifies as a valid input for the model. The expert input of the flags also validate them as plausible indicators for this scenario.

Feedback on *Same Old Oil* notes that Mozambique and Tanzania are acquiring offshore patrol capability at a very slow pace.

6.3.6 Location Factors

Input was required in the form of indicating a level of importance, on a scale from 0 to 2, on the table provided. 0 indicating no importance as a location criteria; 1 citing importance; 2 indicating a very important factor. The second input required the reader to select which location would perform better regarding that specific factor.

An example of a potential environmental section could reflect a readers opinion that "climatic operating conditions" are very important and that Durban (DBN) has a climatic advantage over SMST. Secondly, the reader thinks that governmental regulations are not applicable to location planning as subsequently leaves the ranking section empty. Table 6.7 expresses the averaged opinions of all the interviewees.

		Importance			Location	
		0	**1**	**2**	**SMST**	**DBN**
2	**Environmental**					
	Climatic operating conditions			X		X
	Governmental regulations	X				

From the data questionnaires it became clear that certain location factors that are considered important in the public sector, are not perceived as important in the context of military facility location. Evident by the lack of sensitivity to wards factors such as the economic impact on the community, environmental regulations, community acceptance, traditional grass roots as well the prevention of deterioration of existing facilities. The factors identified as relevant will be considered in conjunction with the model solution to determine the preferred solution to the research question.

Notable Feedback: NBD is perceived by experts as having the overall advantage with regards to climatic operating conditions. However, feedback from the questionnaires issued to more technical experts have expressed concern that the climatic operating conditions in Durban are everything but ideal for equipment and weapon systems.

Table 6.7: Averaged expert opinion on relevant factors for naval facility location.

		Importance			Location	
		0	**1**	**2**	**SMST**	**DBN**
1	**Economic**					
	Access to supplies / resources			X	X	X
	Access to skilled labour			X	X	
	Contribution to security narrative			X	X	
	Cost of upgrading facility			X		X
	Distance to local theatres		X		X	
	Distance to regional theatres		X			X
	Dockyard efficiency		X		X	
	Economic impact on community	X				
2	**Environmental**					
	Climatic operating conditions		X			X
	Governmental regulations	X				
3	**Political**					
	Co-operation with local industry			X		X
	Changing vision of organisation		X	X		X
4	**Social**					
	Availability of housing			X		X
	Adaptation of families			X		X
	Cost of living			X		X
	Community attitude / acceptance	X				
	Schools or universities		X		X	
	Supernumerary personnel		X			X
	Traditional Indian grass roots	X				
5	**Strategic**					
	Air-force support		X		X	
	Fully independent support ability		X		X	
	Prevent deterioration of NSD	X				
	Protecting key-point harbours		X			X
	Second base			X		X

6.3.7 Ranking of Location Categories

Lastly, for weighing purposes, the experts were requested to rank the main categories of location factors in number of importance. The results were the following in ranked order:

1. Strategic
2. Economic
3. Political
4. Environmental
5. Social

From the ranking it is clear that the strategic factors outrank economic, political, environmental and social factors.

6.4 Model Validation

The validation of the model and the case study results will be conducted in two steps, firstly a visual inspection of the facility locations and theatre assignments will take place for each scenario. Thereafter the mathematics of each scenario will be validated using Microsoft Excel.

6.4.1 Visual Inspection

A classic approach to the visual inspection of the model is problematic as the optimal facility layout for each scenario is similar given the validated inputs. Therefore the input parameters were changed to those produced by the sensitivity analysis in Chapter 5. The objective is a lopsided increase in costs to locate a facility in NBS, encouraging the model to locate facilities in NBD for scenario 1. Since scenario 3 could serve as the opposite of scenario 1 it will be subjected to the same data to see if the model makes the logical decision to place the necessary facilities in NBS. From the sensitivity analysis it became evident that a transit speed input of 9 knots will be sufficient to promote facilities at NBD. The lingo results obtained for Scenario 1: Unpaid Vacation Leave, with a transit speed input of 9 knots, are visualised in the following figures:

Figure 6.3 shows a Level 3 facility in Durban with Level 2 and 3 demand from the ELT, EEZ 1 and 2 assigned to it. Figure 6.4 presents the Lingo output for Scenario 1, binaries Y442 and Y443 state that a Level 2 and Level 3 facility is situated in Area 4, hence Durban (EEZ 2). Y332 and Y333, being

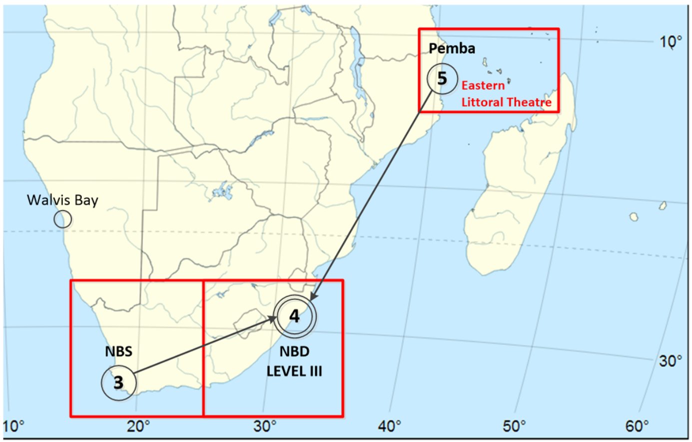


Figure 6.3: Visual representation of theatre assignments for Scenario 1.

equal to zero, shows that no Level 2 or 3 facility is considered in SMST. All the results make sense as NBD is in a better position to service the ELT. Therefore the model passes visual inspection with regards to Scenario 1.

Lingo Output: Scenario 1 @ 9knts		
Variable	Value	Reduced Cost
M	628144700.00	0.00
Y332	0.00	0.00
Y333	0.00	237096600.00
Y442	1.00	0.00
Y443	1.00	0.00

Figure 6.4: Lingo outputs for Scenario 1: Unpaid Vacation Leave validation.

Figure 6.5 shows a Level 3 facility in SMST with Level 2 and 3 demand from the Gulf of Guinea, WLT, EEZ 1 and 2 assigned to it. Figure 6.6 presents the Lingo output for Scenario 3, binaries Y332 and Y333 state that a Level 2 and Level 3 facility should be situated in Area 3, hence SMST (EEZ 1). Y442 and Y443, being equal to zero, shows that no Level 2 or 3 facility should be considered in Durban. All the results make sense as NBS is in a better position to service the Gulf of Guinea and WLT. Therefore the model passes visual inspection with regards to Scenario 3.

6.4.2 Mathematical Validation

The mathematical validation will follow a methodical approach by comparing the Lingo results of each scenario individually with an identical excel model, hoping to acquire the exact same objective function.

The first scenario tested positive as the excel model provided the same objective function, i.e. the minimum cost of meeting operational demand, as the

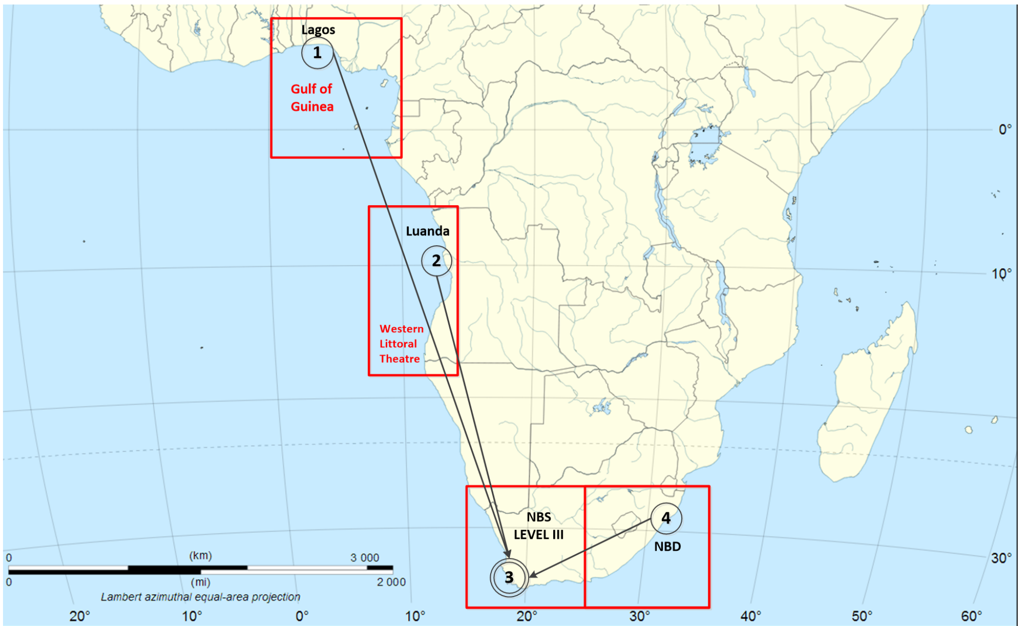


Figure 6.5: Visual representation of theatre assignments for Scenario 3.

Lingo Output: Scenario 3 @ 9knts		
Variable	Value	Reduced Cost
M	815476000.00	0.00
Y332	1.00	0.00
Y333	1.00	0.00
Y442	0.00	0.00
Y443	0.00	341788600.00

Figure 6.6: Lingo outputs for Scenario 3: The Wild West validation.

Excel Model for Scenario 1 @ 14knts			
TC34	33653198	4206649.714	C34
TC35	191514703	10639705.71	C35
V2	110341000		
V3	179105000	289446000	
	514613901		
D34	1538	8	a34
D35	3890	18	a35

Lingo Output: Scenario 1 @ 14knts		
Variable	Value	Reduced Cost
M	514613900.00	0.00
Y332	1.00	0.00
Y333	1.00	0.00
Y442	0.00	0.00
Y443	0.00	0.00
C43	4206650.00	0.00
C53	10639710.00	0.00

Figure 6.7: Mathematical validation of Scenario 1: Unpaid Vacation Leave.

Lingo model. C34 and C35 are the transit costs per voyage to the facility from the relevant operating theatres and back, comprising of the distance D34 and D35 divided by the sailing speed (14 knots) and then multiplied by the cost per hour sailing (R38 292). TC34 and TC35 are the products of the transit cost and demand, in other words the total transit costs for 5 years. V2 and V3 denote the operational costs of a Level 2 and 3 facility in SMST respectively.

Note that the cost of operating a Level 3 facility includes the cost of a Level 2 facility.

Excel Model for Scenario 2 @ 14knts			
TC32	163353672	9075204	C32
TC34	33653197.7	4206649.714	C34
TC35	191514703	10639705.71	C35
V2	110341000		
V3	179105000	289446000	
	677967573		
D32	3318	18	a32
D34	1538	8	a34
D35	3890	18	a35

Lingo Output: Scenario 2 @ 14knts		
Variable	Value	Reduced Cost
M	677967600.00	0.00
Y332	1.00	0.00
Y333	1.00	0.00
Y442	0.00	0.00
Y443	0.00	0.00
C23	9075204.00	0.00
C43	4206650.00	0.00
C53	10639710.00	0.00

Figure 6.8: Mathematical validation of Scenario 2: More Steam.

The second scenario tested positive as the excel model provided the same objective function, i.e. the minimum cost of meeting operational demand, as the Lingo model. C32, C34 and C35 are the transit costs per voyage to the facility in area 3 from the relevant operating theatres and back, comprising of the distance D32, D34 and D35 divided by the sailing speed (14 knots) and then multiplied by the cost per hour sailing (R38 292). TC32, TC34 and TC35 are the products of the transit cost and demand, in other words the total transit costs for 5 years. V2 and V3 denote the operational costs of a Level 2 and 3 facility in SMST respectively.

Excel Model for Scenario 3 @ 14knts			
TC31	186531273	14348559	C31
TC32	117977652	9075204	C32
TC34	33653197.7	4206650	C34
V2	110341000		
V3	179105000	289446000	
	627608122		
D31	5246	13	a31
D32	3318	13	a32
D34	1538	8	a34

Lingo Output: Scenario 3 @ 14knts		
Variable	Value	Reduced Cost
M	627608100.00	0.00
Y332	1.00	0.00
Y333	1.00	0.00
Y442	0.00	0.00
Y443	0.00	360484800.00
C31	14348560.00	0.00
C32	9075204.00	0.00
C34	4206650.00	0.00

Figure 6.9: Mathematical validation of Scenario 3: The Wild West.

Once more the formulation tested positive as the excel model provided the same objective function for scenario 3, i.e. the minimum cost of meeting operational demand, as the Lingo model. C31, C32 and C34 are the transit costs per voyage to the facility in area 3 from the relevant operating theatres and back, comprising of the distance D31, D32 and D34 divided by the sailing speed (14 knots) and then multiplied by the cost per hour sailing (R38 292).

TC31, TC32 and TC33 are the products of the transit cost and demand, in other words the total transit costs for 5 years. V2 and V3 denote the operational costs of a Level 2 and 3 facility in SMST respectively.

Excel Model for Scenario 4 @ 14knts			
TC34	33653197.7	4206650	C34
V2	110341000		
V3	179105000	289446000	
	323099198		
D34	1538	8	a34

Lingo Output: Scenario 4 @ 14knts		
Variable	Value	Reduced Cost
M	323099200.00	0.00
Y332	1.00	0.00
Y333	1.00	0.00
Y442	0.00	0.00
Y443	0.00	360484800.00
C34	4206650.00	0.00

Figure 6.10: Mathematical validation of Scenario 4: Same Old Oil.

Following in the success of the previous validations, the excel model provided the same objective function for scenario 4 as the lingo model. C34 presents the transit costs per voyage to the facility in area 3 from the relevant operating theatres and back, comprising of the distance D34, divided by the sailing speed (14 knots), and then multiplied by the cost per hour sailing (R38 292). TC34 is the product of the transit cost and demand, in other words the total transit costs for 5 years. V2 and V3 denote the operational costs of a Level 2 and 3 facility in SMST respectively.

6.5 Chapter Summary

In order to validate the derived results, a two-step process was followed. First, the inputs of the model were validated using an interview process to extract expert opinion on the data proposed. The second part of the chapter evaluates the results and subjects the model to two phases of validation, namely visual inspection and mathematical comparison.

At the start, the chapter is placed in context with Chapter 5, explaining that Chapter 6 should be actually be placed parallel with the case study chapter, although it follows afterwards in the layout of this thesis. Following the orientation, some literature on validation is briefly discussed, permitting the data confirmation method to be classified as a structured self-administered questionnaire.

To gather and validate the data needed to run the model, a questionnaire was issued to experts in the technical, logistical and combat fields of the SAN. Seven experts in total were identified and presented with a questionnaire; this document can be found in Appendix B as well as a completed example. The questionnaire was issued to specific experts, equivalent to deputy-director level or higher where possible, as not to pollute the data. Objectives were set to extract the interviewees' expert opinions and recommendations on the applicability of the demand areas identified and the scenarios presented.

The objectives of the questionnaire were the following:

1. Validate present and future demand areas.
2. Validate scenarios.
3. Provide probability input for scenarios.
4. Validate selection of location criteria.
5. Provide ranking of location criteria.

Section 6.3 discusses the feedback received from the questionnaires. The result was generally favourable with an averaged basic agreement on the majority of the proposed demand areas. However, from the feedback it became evident that two of the six demand areas are not, in the opinion of experts, possible futures areas of operation for the SAN. These two areas are the Namibian Fishing Zones and the Strait of Hormuz, although conflict in the latter could have a significant impact on the domestic security of South Africa.

In the same section, the four scenarios used as inputs in Chapter 5 were validated along with their flags, after which the experts were asked to input the probability of such a scenario realising for the SAN. These probabilities were then averaged and used as inputs in the case study. The validation of the scenarios did not go as well as the validation of the demand areas. Only Scenario 1: Unpaid Vacation Leave received an average and majority input citing basic agreement. Basic agreement with the first scenario was expected as it reflects the current situation of the SAN, whereas the other scenarios took some extra consideration and was subject to more opinionated input. The other scenarios each scored an average input in the region between basic agreement and basic disagreement, but always more towards agreement. Simply put, in each case the majority of the experts agreed with the scenario and the flags. Therefore all the scenarios qualified as model inputs.

The last subsection dedicated to model input validation intends to confirm and rank a proposed set of subjective location criteria. The experts were requested to state agreement or disagreement with certain location factors categorised as either economic, environmental, political, social or strategic. In conjunction with agreement the interviewee was requested to indicate which location, either SMST or Durban would perform better regarding that specific factor. The result was a strong indication that factors such as the economic impact on communities, governmental regulations, community acceptance, traditional grass roots and prevention of structural deterioration were not considered important factors when military facility location is considered.

The second part of the chapter deals specifically with the validation of the model in two phases, namely visual inspection and mathematical comparison. A classic approach to the visual inspection of the model was problematic as the optimal facility layout for each scenario is similar given the validated inputs. Therefore the input parameters were changed to those produced by the sensitivity analysis in Chapter 5. The objective was a lopsided increase in costs to locate a facility in NBS, encouraging the model to locate facilities in NBD for Scenario 1. Scenario 3 was then visually compared to Scenario 1 to see if the model creates the logical facility pattern based on the demand either on the East or West coast. The visual inspection concluded that the model is logically sound and validation process could continue.

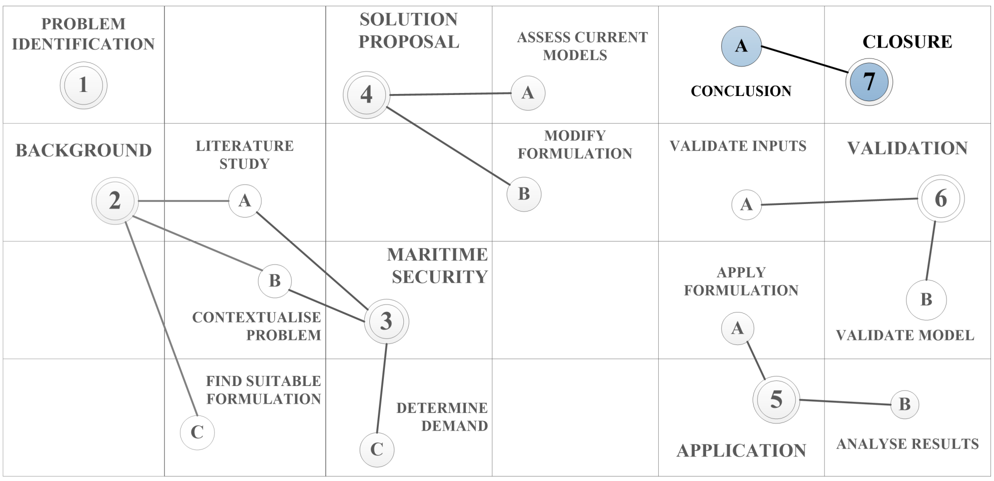
Subsequently and lastly, the model was subjected to a mathematical comparison with a simpler but independent Excel model. Each scenario was validated for mathematical errors by comparing the objective function of the Lingo model with the Excel result. All four scenarios tested positive to the mathematical validation.

Chapter 7

Closure

Chapter Aim:

The aim of this chapter is to convey the research findings into a final conclusion. In addition, the chapter discusses the results in a broader strategic framework than permitted by the research scope. Lastly, the chapter makes general managerial recommendations as well as recommendations for future research.



Chapter Outcomes:

- A summary of work done.
- Final conclusion in broad strategic framework.
- Answer to the central research question.
- Define state of the null hypothesis.
- Recommendation for future research.

7.1 Summary of Work

This thesis contains five main bodies of work of which the first is a comprehensive review of facility location and strategic management. From this literature domain it became clear, due to the multi-level maintenance component, that the research problem could be classified as a *hierarchical location-allocation problem*. The stochastic nature of real-world facility location problems, combined with the limited resources of this research, encouraged the use of scenario planning as an input mechanism. In summary, Chapter 2 provides the majority of the literature study for this thesis in the Operations Research (OR) domain.

The next considerable contribution is a chapter focused on the physical and financial environment of the SAN. Chapter 3 addresses the concepts of maritime security in general as well as in the South African context. Within the context of this chapter six potential, present or future, areas of interest to the SAN were identified. These areas are: the Gulf of Guinea, the Western Littoral Theatre (WLT) or Angolan waters, Namibian Fishing Zones, South Africa's Economic Exclusive Zone (EEZ), the Eastern Littoral Theatre (ELT) or Mozambican Channel and the Strait of Hormuz.

The third substantial body of work done in this thesis is the combination of two well established formulations to create theoretical mechanism to solve the research objective. For that reason, Chapter 4 proposes a model that combines existing hierarchical formulation from Calvo and Marks (1973) and Tien *et al.* (1983) with scenario based formulation from Marianov and Serra (1998).

The final two bodies of work, although they are presented in sequence, proceeded in parallel as they are dependant on each other for data. Chapter 5 employs the developed facility location model to a suitable and relevant problem. In essence, the chapter applies the formulation to determine if the SAN should reinstate one of their scaled-down naval bases to accommodate a new type of multi-role patrol vessel. As mentioned, the data inputs for Chapter 5 were validated in the first part of Chapter 6. The second part of the validation chapter evaluates the results from Chapter 5 and subjects the model to two phases of validation, namely visual inspection and mathematical comparison. The final body of work concludes that the model tested positive to both forms of validation and that the results of the case study qualified for analysis.

7.2 Conclusion

The main focus of this section will be the analysis and review of validity of the results obtained in Chapter 5. To start, the input scenarios, comprising of demand areas and their probabilities of realising respectively, were validated as positive in Chapter 6. The subsequent datasets were inserted into the formulation along with a distance matrix, adjusted for patrols en route to destination, transit speed data and fixed, operational and sailing costs data.

The results of the model was conclusive that re-establishing any capability above 1st Line support in Durban, purely for the possible requirements brought by "project BIRO", is not optimal in terms of cost. The application of the developed model, which minimises the cost across multiple scenarios, seemed unnecessary as the scenario most probable to favour 3rd Line support in Durban responded negatively in isolation. Simply put, a scenario, with a 100% probability of realising for the next 15 years, in which the SAN operates solely in its own waters and in the Mozambican Channel (ELT) does not justify the establishment of 3rd Line capability in Durban.

A sensitivity analysis was done on that scenario alone, thus negating the other three scenarios which places possible future demand along the west coast of Africa. This gave insight into the following input parameters; the transit speed used in the model is 14 knots, only if the transit speed decreases to below 10 knots does the model prefer facilities in Durban; only if the averaged cost of transit rises above R53 641 per hour sailing does the model prefer facilities in Durban; additional investment or operating costs of R29.957 million in SMST or a dramatic increase in demand in the ELT would promote facilities in Durban. Bear in mind that these parameters would only be of importance if the SAN does not consider any future participation in theatres on the west coast of Africa.

There are off course other considerations when locating facilities, especially in the strategic context. Having a second, independent support base in South Africa's most important port should be considered in terms other than pure economics. To compliment this discussion, Table 7.1 which summarises subjective location factors to be considered, has been derived from expert input in Chapter 6. Of all the factors listed in the table, Durban is perceived to be superior to SMST in the following:

· Distance to regional theatres (ELT),

· Climatic operating conditions,

· Cooperation with local industry,

· Availability of housing,

· Adaptation of families,

- Cost of living,
- Supernumerary personnel,
- Protection of key-point harbours,
- Strategic importance of having a second base.

In addition to the aforementioned, in Chapter 5 a cost comparison was drawn between the two options on a 5 year and 15 year scale. The result was a total cost difference (loss) of roughly R210 million over 5 years to establish 3rd Line capability in Durban. Over 15 years this cost difference increases to roughly R500 million. Both these costs were adjusted for inflation[1] and it should be noted that the costs applicable to Durban are lower bound costs. In other words, they only include the technical component of establishing full 3rd Line capability in Durban, the costs of establishing a fully independent base will be much more. The question then becomes: if it has been proven that re-instating Durban to a naval base it not economically optimal, do the perceived benefits mentioned justify the R210/500 million (1.58%[2] of allocated budget over period) cost, keeping in mind that most of such costs will be employee compensation?

To continue, the SANDF has, for over two decades, experienced a decrease in military spending as a percentage of GDP. Although the Defence Budget Vote for the 2013/14 financial year amounts to R40,243 billion (US $3.945 billion)[3], this equals 1,1% of GDP and 3,8% of total government expenditure 2013. Thompson *et al.* (1996) advises that organisations operating in slow-growth/declining environments, such as the SANDF, have to accept the realities of such an environment and resign themselves to objectives coherent with available opportunities, one such objective being a strong focus on cost reduction.

Thompson *et al.* (1996, 180) lists some prerequisites for crafting successful strategies, it would be highly advisable for an organisation like the SANDF to adhere to their implied concepts:

1. *Avoid strategies capable of succeeding only in the most optimistic circumstances.* Read continued operations only in the ELT,thus expect unfavourable operating conditions.
2. *Be cautious of inflexible strategies that leave little space for manoeuvring.* Inflexible strategies can quickly be made obsolete by changing conditions.

[1]Costs were adjusted for inflation at a fixed rate of 5%.
[2]Taken as R2.4 billion per year for 5 years and adjusted for inflation at 5%.
[3]Using exchange rate of 1 USD = 10.2 ZAR, 30 November 2013.

Table 7.1: Relevant factors to naval facility location.

1	**Economic**
	Access to supplies / resources
	Access to skilled labour
	Contribution to security narrative
	Cost of upgrading facility
	Distance to local theatres
	Distance to regional theatres
	Dockyard efficiency
2	**Environmental**
	Climatic operating conditions
3	**Political**
	Co-operation with local industry
	Changing vision of organisation
4	**Social**
	Availability of housing
	Adaptation of families
	Cost of living
	Schools or universities
	Supernumerary personnel
5	**Strategic**
	Air-force support
	Fully independent support ability
	Protecting key-point harbours
	Second base

To add to the financial background of the SAN, in FY 2010/11 the compensation of employees in the SANDF rose to 55% of the total allocation (Meyer, 2012). This percentage conflicts with the 40% margin[4] pegged in the 1998 defence review, resulting in the exceeding 15% being drawn from the operational and capital allocation, effectively negating the operational capability of the SANDF. Some experts believe that the percentage of budget spent on employee compensation in the SAN could be as high as 70 % with the high amount of work being outsourced.

The ultimate question then being, can a financially constrained organi-

[4]The 1998 Defence Review pegged the defence personnel budget at 40% of the total budget with 30% to be spent on operating costs and the remaining 30% to be spent on capital costs (40:30:30 ratio).

sation like the SAN, already plagued by overspending on salaries, afford to employ almost 800 people to give the SAN the subjective advantages listed. In accordance with literature on strategic management the answer should be no. Commitment to salaries causes inflexibility as people are more easily hired than fired and bases more easily opened than closed. Although Naval Base Simon's Town (NBS) is not optimally placed to serve either coast, it is in the optimal position to serve both, therefore the case study concludes that the necessary investments be made to accommodate the new vessels in SMST. This statement answers the main research question posed in Chapter 1. Consequently the null hypothesis, as stated in Section 1.2, is accepted.

H_0:	The SAN cannot cost-effectively meet its future operational obligations by splitting its maintenance capability between NBD and NBS.

The acceptance of the null hypothesis accounts for the achievement of the final research objective. Throughout the progression of this thesis, every research objective was accomplished, eventually resulting in a comprehensive answer to the stated research question. The thesis concludes with the provision of recommendations and motivation for future research.

7.3 Recommendations

The following recommendations are made with respect to "project BIRO" as the acquisition of new vessels drives the *raison d'être*[5] for this thesis. This is due to the fact that the failure of BIRO to realise could put extra pressure on the SAN to relinquish its regional responsibilities. With that in mind, the recommendations follow two strategies; one of contingency should BIRO fail and one of assisting BIRO to be realised. Of course both these recommendations can be considered in unison.

1. The SAN should incur the necessary costs to staff the vacant posts in SMST of both FMU and Dockyard. This will serve the duel purpose of providing the man hours needed for to effectively service the current vessels whilst providing the increased capacity needed should BIRO be realised. Southern African Shipyards can be utilised for upkeep support in Durban.

[5]The claimed "reason for the existence" of something or someone; the sole or ultimate purpose of something or someone.

2. To increase the possibility of "Project BIRO" being realised, the SAN should work with other Sub-Saharan African countries in the design process to derive a generic OPV design. Such a vessel should incorporate the requirements of any African country considering to operate it, albeit in the considerable future. A generic OPV combined with better regional relations could result in considerable cost savings in acquisition, maintenance, training and staffing for Sub-Saharan Africa as a whole. This sketches a future scenario in which South Africa, Nigeria, Angola, Tanzania and Mozambique all operate one generic OPV. The majority of the vessels will probably be constructed in Nigeria and South Africa, who would also be operating the majority of the vessels. Littoral countries that cannot operate these vessels in their own capacity could send military personnel to train with other navies to build a domestic reserve of competent sailors. These sailors could then be called up as the need arises or when vessels in need of personnel pass that specific country. Imagine a future situation where such a vessel leaves SMST, and en route to the WLT, picks up any needed personnel in Walvis Bay before it arrives in the patrol theatre and drops them off after the deployment. Even better would be if half those Namibian sailors could stay behind and board the incoming Nigerian OPV, complementing its crew and sharing experiences of the previous deployment. The main objective being to couple the prospects of "Project BIRO" to the emerging economies of northern Africa.

Following these two recommendations will not necessarily guarantee the realisation of "Project BIRO" or seal the fate of Naval Station Durban (NSD) but place the SAN in a relatively strong strategic position to postpone any such decision until more favourable circumstances or opportunities reveal themselves.

This view is supported by Owen and Daskin (1998, 435), who acknowledge that the difficulty in solving facility location problems arises from the uncertainty of future conditions. They argue that the best way to manage uncertainty is to postpone the decision making as long as possible. Since the first period decisions are the only ones that take immediate effect, Owen and Daskin (1998) claim that the goal of location planning should be to find an optimal or near-optimal first period solution for the problem over an infinite horizon. Simply put, determine the optimum starting location with near-future certainties, then collect information and update forecasts as time advances to determine when to expand or relocate.

To conclude, Thompson *et al.* (1996) advise to defend one's organisation against current and future threats. External threats could, in the context of public agencies, be a decrease in budget. In the same breath, pursuing opportunities without the organisational competencies and resources to take complete advantage of it is not advisable.

7.4 Future projects

During the research process some considerations emerged that may be worth of further investigation. The recommendations for future research encompass three suggestions:

1. A more comprehensive optimisation, one that includes the preventive maintenance schedules of the Navy's submarines and frigates, would be beneficial to answering the research question more thoroughly as they should have lower transit speeds and higher transit costs respectively than the new OPV's. As the sensitivity analysis showed in Chapter 5, these two factors (speed and cost) have a considerable economic impact on the desire to reinstate Durban.

2. The location factors stated can be investigated in terms of cost, or a cost could be subjectively assigned to them to include them in the optimisation formulation. Once again resulting in a more comprehensive solution.

3. If possible and if regional relations permit, a complete cost model could be incorporated, meaning that the cost of establishing facilities of level h in any operational theatre should be inserted into the model. The result would be...

   *an optimal hierarchical facility pattern that would guarantee minimum cost to **all Sub-Saharan** countries regarding their **continental** and domestic obligations whilst complementing the social benefit of the **region as a whole**.*

Appendices

Appendix A

Projects and Operations

A.1 Operation Corona

Operation Corona is the return of the South African National Defence Force (SANDF) to the borders of South Africa with effect from April 2010. The return to the borders was effected in a five-phase approach over a period of four years with a total of twenty-two (22) infantry companies. At the end of the full deployment, it is estimated that the SANDF would cover 4 471 kilometres of land border, 2 700 kilometres of maritime border and 7 660 kilometres of air border.

The outline of the SANDF's landward border protection roll-out plan consisted of the following phases:

- Phase 1 (2010/2011). This phase ended in March 2011 with four infantry companies already deployed on the North-East Zimbabwe and Mozambique borders. Two engineering troops were deployed in support to repair border fences.
- Phase 2 (2011/2012). This phase started in the new financial year (April 2011) and includes the deployment of three companies to the Kruger National Park (Mozambique), Lesotho and Swaziland borders respectively.
- Phase 3 (2012/2013). Four additional companies will deploy on the Zimbabwe, Lesotho and Swaziland borders.
- Phase 4 (2013/2014). The focus in this deployment will be on the Botswana/ Namibian borders, but will also include deployments on the Lesotho border.
- Phase 5 (2014/2015). Deployments will concentrate along the Botswana and Namibian frontiers. Additional deployments will include Swaziland

and Mozambique. By this time all twenty-two (22) companies would be deployed and safeguarding South Africa's land borders.

A.2 Operation Copper

The growing global effort to counter piracy in the Indian Ocean has forced pirates to shift their efforts south, evident in the 17 acts of piracy that occurred in Tanzanian waters in 2011. This has forced the Southern African Development Community (SADC) to react and in the same year the South African Cabinet approved the deployment of the SAN to combat piracy. This was after the governments of South Africa, Mozambique and Tanzania entered into a trilateral maritime security agreement, named Operation Copper. Mozambique and Tanzania contribute manpower and equipment for sea patrols led by the SAN. This development also comes as Norwegian energy company Statoil announced a significantly large discovery of natural gas offshore of Tanzania, leading to an increased need for stability in the area. To increase the efficiency of Operation Copper, the SAN is considering refurbishment and reinstatement of Naval Station Durban on Salisbury Island to some of its capacity as a full naval base and moving the anti-piracy operations from Simon's Town to Durban.

A.3 Project BIRO

The 2012 Defence Review affirmed that the SAN should have a force design much larger than it currently retains. A key variance is the omission of a Patrol Craft and Mine Counter Measure Vessel MCMV component. To compensate, the Navy developed a single programme to acquire multi-role vessels that would replace the MCMVs and provide a sufficient patrol capability. Hence Project BIRO was born.

The concept for BIRO is the acquisition of a combination of Offshore Patrol Vessel (OPV)s and Inshore Patrol Vessel (IPV)s that can be operated as platforms for different modular systems. Meaning that different containerised systems, being Mine Countermeasures (MCM), surveillance or more attack orientated as in the case of a main gun, can be quickly interchanged between platforms. Thus a vessel that was outfitted primarily as a patrol vessel can be converted into a MCMV within a short period of time, giving flexibility both to the maintenance and deployment of the vessels. Ultimately this eliminates the need to build dedicated vessels for each role but to have vessels that can assume a particular role when needed. The Royal Danish Navy has successfully employed this concept in its "Stan Flex" family of warships.

The *Flyvefisken* Class (SF 300) was the original modular warship using a standard hull with containerised weapon systems and equipment. This design allowed the vessels to change roles quickly. Weapon and equipment containers can be exchanged within one hour and systems can be aligned and calibrated within a few hours. The command system, radar and hull-mounted sonar are standardised to allow maximum utilization of crew.

The SAN is hoping for the same success in employing the modular concept in its OPVs but is looking at further reducing costs and development time by deploying a more commercial hull design and fitting of military off-the-shelf equipment. The physical properties of the vessels will be relevant in determining the level of investment required to provide each facility with the necessary infrastructure the service such vessels.

The proposed vessels are required to operate unsupported for a maximum of 21 days and will make use of a more commercial hull design. Off-the-shelf military equipment will be used as far as possible with redundancy only for mission critical systems.In addition to a helicopter operating ability, the vessels will need to carry smaller boats to transfer boarding parties to suspect vessels. Operations of this nature are referred to as Maritime Interdiction Operations (MIOs), generally initiated by transferring smaller boats into the ocean with a davit mechanism. The requirements are summarised in Tables A.1 and A.2. Relevant to the model is the endurance and the speed profile of the patrol vessels (Table A.3). At the time of writing, the SAN requirements regarding project BIRO were the following (Fish, 2013).

Table A.1: Inshore Patrol Vessel (IPV) Requirements

Property	**Requirement**	**Unit**
Length	55 -60	meters
Helicopter	YES	-
Hangar	NO	-

Table A.2: Offshore Patrol Vessel (OPV) Requirements

Property	**Requirement**	**Unit**
Length	85 -90	meters
Displacement	1500-2000	tonnes
Maximum speed	20	knots
Helicopter	YES	-
Hangar	YES	-
MIO	YES	-
Crew	30-45	-
Endurance	21	days

Table A.3: Offshore Patrol Vessel (OPV) Operating Profile

Speed (knots)	**Time (% of Life)**	**Profile**
≤ 6	10 %	Special mission
6-10	40 %	Economic speed
10-14	35 %	Economic transit
14-17	10 %	High speed transit
17- max	5 %	Interception

Appendix B

Model Validation

B.1 Data Questionnaire

B.1.1 Introduction

The South African Navy (SAN) intends to reinstate Naval Station Durban (NSD) back to Naval Base Durban (NBD), i.e. a fully operational support and training base for the planned acquisition of a new class of Offshore Patrol Vessels (OPVs). The need to reinstate NBD, although arisen from deeper strategical and political needs, is driven by the local re-emergent threat of piracy, and the consequential planned acquisition of new multi-role patrol vessels to, amongst other things, specifically combat this threat.

If operations in the Eastern Littoral Theatre (ELT), namely the Mozambican Channel, are to be maintained for the unforeseeable future, a sustainable support strategy must be implemented. Currently the only fully operational Naval Base available to the SAN is located in Simon's Town, near the southernmost tip of Africa. It is in the ideal location to support operations in both the Indian and Atlantic Oceans but not optimal for either (Schäfer, 1998).

B.1.2 Problem Statement

Before the scaling down of NBD, the scope of the base's capabilities and capacity [1] equalled that of a small independent navy. It was home to the Strike Craft Flotilla, Dockyard Durban, SANAD Durban, SCTC and Radio Station Umdhloti. The Dockyard had a very powerful technical support capability that provided 2nd line and some 3rd line support to other elements of the SAN and full 3rd line and some 4th line support to the strike craft (Capt.(SAN) Dooner

[1]Capability vs Capacity. Capability considers what can be, or needs to be, done. Capacity considers how much can be done by a capability. As an example; While NSD has the capability required to fault find on WARRIOR class ELM 2208 search radars, it does not have the capacity to do so simultaneously on all 3 in inventory.

and Capt.(SAN) Patrick, 2012).

Relevant to this thesis is the potential restoration of the Maintenance and Repair capabilities to Durban, and the subsequent restoration or relocation of needed facilities and equipment. This process includes but is not limited to, the allocation of required personnel, addition or relocation of equipment and the constraints directly impacting the provision of efficient support to future OPV's. The opportunity costs associated with having these resources available only in NBS, and possibly have private companies maintain the ships in Durban have to be considered.

The overall problem being:

of what level (line) of maintenance should the equipment, workshops and facilities in Durban be capable, to optimally support the new patrol vessels, be it fully independent, in conjunction with or fully reliant on the capabilities of Simon's Town or a private company

The purpose of this thesis is to determine the optimal layout in maintenance capabilities between NBS and NBD whilst examining the factors that impact, drive and constrain the addition or relocation of maintenance capabilities to NBD. Facility Location theory will be used to determine the optimal relationship between support facilities, be it in SMST, NBD or function as a network (*location and allocation problem*) between the two over an infinite horizon.

B.1.3 Objectives

The objective of the thesis is to ultimately find:

an optimal hierarchical facility pattern that would guarantee minimum cost to the organisation regarding its regional and domestic strategic obligations whilst complementing the social benefit of the affected region.

The objectives of the questionnaire are the following:

1. Validate present and future demand areas.
2. Validate scenarios.
3. Provide probability input for scenarios.
4. Validate selection of location criteria.
5. Provide ranking of location criteria.

B.1.4 Approach

The blueprint of the solution approach is shown in Figure B.1, doubling as a layout for this handout. Firstly, from literature on security studies, more specifically maritime security, present and future demand areas were identified. From this context, scenarios were drawn up representing possible variation in demand and designated theatres of operation. Probabilities are then assigned to each scenario in accordance with the scenario model developed by Clem Sunter (2012). These scenarios were then fed into the facility location formulation to produce the *most efficient* solution. The efficient solution is combined with various external location factors to derive the *preferred* solution.

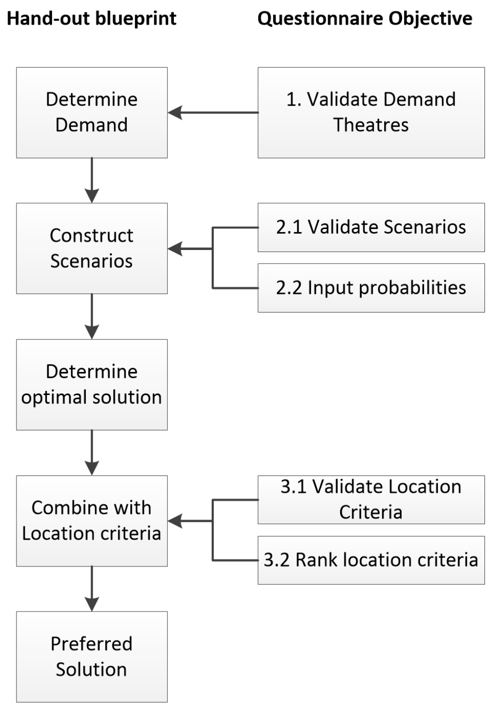


Figure B.1: Layout of Questionnaire

The following sections will require input form the intended reader, it goes without saying that the honest opinion of the reader is sought and space for additional input (which will be greatly appreciated) is provided at the end of each section.

Input is required in the form of indicating a level of agreement, on a scale from 0 to 3, on a provided table. 0 indicating a strong disagreement; 1 citing disagreement; 2 indicating agreement and 3 conveying strong agreement. N/A can be ticked if the reader finds he is unprepared to provide input at this time. An example is provided below for validating the demand areas in which the reader disagrees with a potential demand area:

	Level of Agreement				
	N/A	**0**	**1**	**2**	**3**
Gulf of Guinea			X		

Providing input to the scenarios will work in a similar method, except for the addition of a probability input. An example is provided below for validating the scenarios in which the reader strongly agrees with the scenario and the flags, subsequently he/she assigns a probability of 40%[2] to it:

	Level of Agreement					Scenario 1 Probability
	N/A	**0**	**1**	**2**	**3**	
Scenario 1					X	40 %
Flags					X	

B.1.5 Demand Areas

Demand stems from two main sources; piracy or criminal activity. Demand areas are identified under the assumptions that both piracy and militant activity originates from continental instability of a littoral state. The second assumption is that economic activities will, sooner or later, attract criminals, rebels, terrorists or foreign forces to such unsecured areas of operations. Within this framework, research has identified six, present and/or future, areas of interest to the SAN in the context of maritime security (Figure B.2). Please indicate the level of agreement, i.e. are these areas present, and or future, areas of interest to the SAN in the context of maritime security?

A brief description of the areas or theatres follows:

1. *Gulf of Guinea*: Oil and gas are important elements in the broad African economy, with a high proportion of oil and gas reserves found offshore, on islands or in coastal areas. These reserves are not enormous, but offer significant quality advantages. Being lighter, oil from the Gulf of Guinea is easier and more economic to refine than Middle Eastern crude. Additionally, the continent's strategic location offers decent sea-lanes to the West and East. The exploration of significant resources on new offshore locations offer a potentially stable security environment, on account of their distance from the mainland. The volatility of landward and coastal

[2]The probabilities are of the scenarios realising as of present and have to accumulate to 100 %, with the present scenario having the highest probability. Please see Section B.2 for a clearer explanation

oil-producing facilities is well documented. Given the volumes of African oil being lost, estimated at 200 000 barrels per day (some 10% of daily production (Gambrell, 2013)) in Nigeria alone, due to unrest and conflict. Deep offshore location may offer a way around land-based vulnerabilities and represent a major step towards securing oil flows. Neglecting security can thus unleash a potential arc of conflict stretching from Sierra Leone in the west past the Ivory Coast, Nigeria and down to the Republic of Congo, DRC to Angola in the south. The volatility currently found inland will directly affect the adjacent maritime domain as it is not possible to have maritime security amidst such continental insecurity (Vrey, 2009, 92). Moreover, it is assumed that the port of Lagos will serve as support point should the SAN ever participate in sustained operations in the area.

	Level of Agreement				
	N/A	**0**	**1**	**2**	**3**
Gulf of Guinea					

2. *WLT*: Angola was the world's fastest-growing economy for the first 10 years of the new millennium, averaging a GDP Growth rate of 11.2 percent and reaching an all-time high of 23.2 Percent in December of 2007, and it continues to be amongst the fastest-growing economies on the continent. Angola is Africa's second largest oil producer. As such, oil production is the main sector of the economy, accounting for about 47 percent of total GDP. The majority of Angola's oil production takes place offshore, and for the same reasons as stipulated for the Gulf of Guinea, economic activity combined within an unstable region will attract criminal activity. Given the inadequate capability of the Angolan Navy, it is not unreasonable to assume that they will require support should their maritime region become unstable.

	Level of Agreement				
	N/A	**0**	**1**	**2**	**3**
WLT					

3. *Namibian Fishing Zones*: Although the Namibian Navy has made great strides in the past decade to evolve into a organisation capable of protecting their own interests, they still lack genuine maritime security capability. Therefore it is assumed that the SAN will still retain some of its historic responsibility in patrolling the Namibian Fishing Zones.

	Level of Agreement				
	N/A	**0**	**1**	**2**	**3**
Namibian fishing Zones					

4. *South Africa's Economic Exclusive Zone (EEZ)*: For obvious reasons, the SAN will be required to patrol and safeguard South Africa's maritime sovereignty. The EEZ is a territorial zone stretching 200 nm into the ocean from the South African coastline and includes similar territories around Marion and Prince Edward Islands.

	Level of Agreement				
	N/A	**0**	**1**	**2**	**3**
South Africa's EEZ					

5. *Eastern Littoral Theatre (ELT)*: Operation Copper has shown that the SAN is capable and willing to take on more regional roles. Piracy in the region north of Pemba has somewhat stabilised since the inception of operation Copper but still remains a present threat.

	Level of Agreement				
	N/A	**0**	**1**	**2**	**3**
ELT					

6. *The Strait of Hormuz*: The last potential area of operations is highly unlikely, even more so for a patrol vessel. But war is a reality and presently the Middle East is the most volatile region. Should full-scale conflict erupt between Syria and Israel, drawing in Iran who would consequently close the Strait of Hormuz as threatened, South Africa will stand to lose 40% of its imported oil. The SAN would be forced to take action, even if it only serves to add weight to an international effort to reopen the strait.

	Level of Agreement				
	N/A	**0**	**1**	**2**	**3**
The Strait of Hormuz					

Notes:

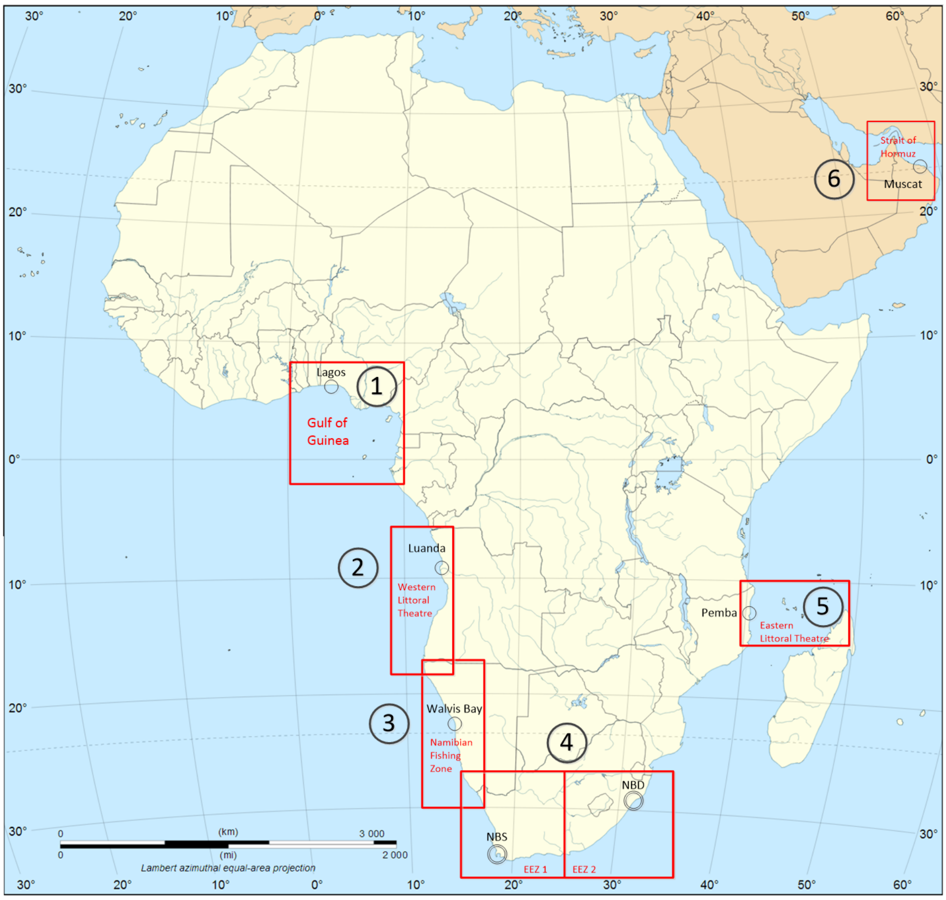


Figure B.2: Graphical presentation of demand areas

B.1.6 Scenarios

The following scenarios are based on the model developed and frequently used by Clem Sunter (2012) in building scenarios. For the more intricate workings of the model, please refer to section B.2, if for anything else it makes for interesting reading. Figure B.3 displays a Game-Board layout of the possible future scenarios considered. The driver axes are distance and demand, both directly contributing to the transit cost of vessels. High demand is defined as a requirement for continuous patrol in the theatre.

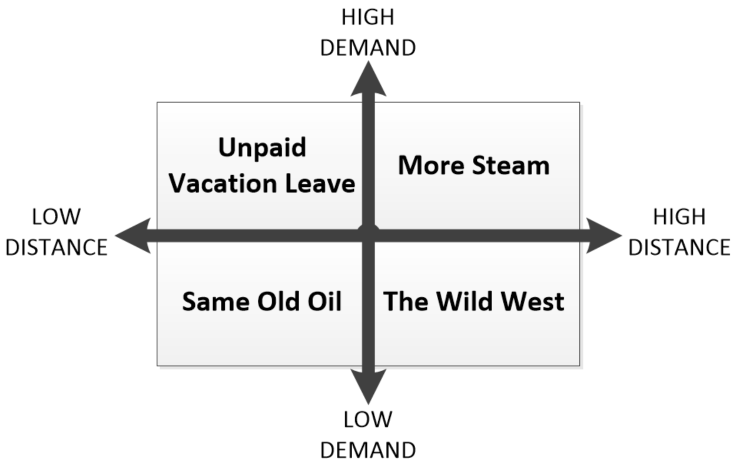


Figure B.3: Proposed scenario game board

1. *Unpaid Vacation Leave*: This scenario is based on the assumption that piracy continues to be a threat in the Mozambican Channel for the next 10 -15 years. This persistence will motivate a need for increased patrol capability, contributing to the motivation for Project BIRO. This scenario is placed in the high demand quadrant as continuous patrol is required owing to the fact that the SAN is the main force contributor. On the economic front, the world and South Africa in particular is still enduring slow economic recovery, implying that the SANDF will for some period still operate in a financially constrained environment. As a consequence, sustainable support is sought for these patrols directly promoting the reinstatement of Durban as a naval base. The following Flags will indicate continuation in "*Unpaid Vacation Leave*" or a move towards it:

   a) Continued or increased piracy related incidents in the Mozambican Channel.

   b) No increased effort from Tanzania or Mozambique to acquire adequate patrol capability.

	Level of Agreement					**Scenario 1 Probability**
	N/A	**0**	**1**	**2**	**3**	
Scenario 1 Flags						

2. *More Steam*: Scenario 2 is basically a convergence of “Unpaid Vacation Leave” and “The Wild West”. In this study “More Steam” also serves as the *worst case* scenario. Criminal activity has established itself on both African coasts, leaving South Africa to split its resources between the WLT and the ELT. South Africa will have to intervene as volatility along the CSR will indirectly affect the cost of maritime trading as ships will evade docking with other countries as they sail along the African coast. Furthermore, the centre of the African economy is shifting north as trading powers no longer see South Africa as the economic key to Africa. Consequently, a popular trade route between Brazil and Nigeria emerges, redirecting critical trade from South Africa. These developments leave the SAN with no options other than to make the Cape Sea Route (CSR) the safest route into Africa, encouraging vessels to make South Africa their first destination. The following Flags will indicate movement towards “*More Steam*”:

    a) The flags of both “Unpaid Vacation Leave” and “The Wild West”.
    b) The re-emergence of the old Atlantic slave route as a viable Sea Lane of Communication (SLOC) between Brazil and Nigeria.
    c) Continued economic growth of Nigeria and Angola, with the former poised to overtake South Africa as Africa’s main economy within the next 20 years, replacing South Africa on the G8 council.

	Level of Agreement					**Scenario 2 Probability**
	N/A	**0**	**1**	**2**	**3**	
Scenario 2 Flags						

3. *The Wild West*: Scenario 3 sees the SAN tasked with assisting in stabilising the southern regions of the Gulf of Guinea instead of the ELT. The economic expansion of Angola has brought vast infrastructure development to their maritime domain. Unfortunately, this economic boom has exceeded the limits of the country’s security capability. Consequently, a potential agreement is initiated, similar to that anchoring Operation Copper, in which the SAN provides patrol support in a operation funded by SADC or ECOWAS. The following Flags will indicate move towards “*The Wild West*”:

    a) Angola’s GDP growth rate continues above 8 % mark, under this growth it is unlikely that their security capability will keep pace.

b) An increase in criminal activity in the region or a southwards shift of the criminal activity already present in the Gulf of Guinea.

	Level of Agreement					**Scenario 3 Probability**
	N/A	0	1	2	3	
Scenario 3 Flags						

4. *Same Old Oil*: This is a reverted state back to the days before piracy in the Mozambican Channel. Piracy in the ELT is starting to subside due to the unified pressure from regional countries, including France. There is also no signs of potential instability along the western coast of Africa. In this scenario the SAN focusses on its domestic obligations, mainly in the line of Operation Corona. Flags indicating a move towards "*Same Old Oil*":

   a) An overall decrease in pirate activity along both coasts of Africa.

   b) A decrease in political will to continue with Operation Copper.

   c) The failure of BIRO to realise could put extra pressure on the SAN to relinquish regional responsibilities.

	Level of Agreement					**Scenario 4 Probability**
	N/A	0	1	2	3	
Scenario 4 Flags						

B.1.7 Location Factors

For proper facility planning, according to Calvo and Marks (1973, 409), an explicit set of social, economic, political and environmental factors should be considered. The suitability of a specific site depends largely on the selection and evaluation of location factors. Unimportant factors, including those which are not site sensitive, should be identified and eliminated from the consideration. Location factors that have been widely used in public location research can be adapted to the context of this thesis and grouped into the following main categories (Yang and Lee, 1997, 242): Economic, Environmental, Political, Social and Strategic (Table B.1).

Table B.1: Facility location factors.

		Importance			Location	
		0	**1**	**2**	**SMST**	**DBN**
1	**Economic**					
	Access to supplies / resources					
	Access to skilled labour					
	Contribution to security narrative					
	Cost of upgrading facility					
	Distance to local theatres					
	Distance to regional theatres					
	Dockyard efficiency					
	Economic impact on community					
2	**Environmental**					
	Climatic operating conditions					
	Governmental regulations					
3	**Political**					
	Co-operation with local industry					
	Changing vision of organisation					
4	**Social**					
	Availability of housing					
	Adaptation of families					
	Cost of living					
	Community attitude / acceptance					
	Schools or Universities					
	Supernumerary personnel					
	Traditional Indian homeland					
5	**Strategic**					
	Air-force support					
	Fully independent support ability					
	Prevent deterioration of NSD					
	Protecting key-point harbours					
	Second base					

The purpose of the table is to determine the importance of the location factors whilst determining which location ranks the best considering that specific criteria. In other words, how important is the relevant factor and which location, Simon's Town (SMST) or Durban (DBN), would perform the best considering the said factor. Input will be required in the form of indicating a level of importance, on a scale from 0 to 2, on the table provided. 0 indicating no importance as a location criteria; 1 citing importance; 2 indicating a very important factor. The second input requires the reader to select which location will perform better regarding that specific factor. To assist the reader, read every factor with the preamble "The *category*(example: economic) importance off ..."

An example of a potential environmental section could reflect a readers opinion in which he feels "climatic operating conditions" are very important and that Durban (DBN) has a climatic advantage over SMST. Secondly, the reader feels that governmental regulations are not applicable to location planning and subsequently leaves the ranking section empty.

		Importance			**Location**	
		0	**1**	**2**	**SMST**	**DBN**
2	**Environmental**					
	Climatic operating conditions			X		X
	Governmental regulations	X				

Note that "Distance to local theatres" and "Distance to regional theatres" will be replaced by the optimisation solution in any decision model. The input requested is just for comparison purposes.

Lastly it would be appreciated if the reader can rank the location factor categories from 1 to 5 in number of importance on the provided table. Whichever category receives the 1 will be denoted the most important category according the reader, receiving a 5 will cite least importance overall.

		Rank
1	**Economic**	
2	**Environmental**	
3	**Political**	
4	**Social**	
5	**Strategic**	

Notes:

B.2 Scenario Crafting

Chantell Ilbury and Clem Sunter[3] have developed a scenario planning technique that presents different scenarios in a matrix, rather than listing them individually. This allows the logical connection between the scenarios to be more easily visualised. The choice of the two axis that form the matrix is crucial, these should be the real driving forces for each scenario. The other modifications they have made to the scenario process are to identify "flags" which indicate movement towards one specific scenario (quadrant); and then, attach a subjective probability to each scenario based on the tendencies of the flags. The flags are constantly monitored to determine the state of the matrix and to adjust the probabilities of all scenarios as soon as a flag is raised.

To better explain both the matrix method and the concept of flags, a scenario developed by Sunter (2012) will be used as an example throughout this section. He named this specific scenario matrix "The global tightrope", which illustrates four possible scenarios (Figure B.4) likely to unfold, according to the various drivers and flags, following the 2008 financial crash. Firstly, the two axis (drivers). The horizontal axis describes the rate of economic recovery as a driver with U denoting a slow and V denoting a quick economic recovery. The top of the vertical axis denotes a global effort and the bottom a world that is becoming increasingly divided.

The interaction between these two axis (drivers) yield four possible scenarios according to Sunter (2012):

1. The first quadrant is "Hard times", a scenario of conventional global recession, i.o.w. slow economic recovery for everyone where unemployment rates remain high for much longer than anticipated. China and India are not spared as their dependencies on the global markets have a domino effect on their economies. Asset prices (property and equities) decrease,

[3]Mr. Sunter was awarded an Honorary Doctorate by the University of Cape Town for his work in the field of scenario planning. He was also voted by leading South African CEOs as the speaker who has made the most significant contribution to, and impact on, best practice and business in South Africa. In 2006, he was invited to give a scenario presentation at the Central Party School in Beijing - a rare privilege for a foreigner.

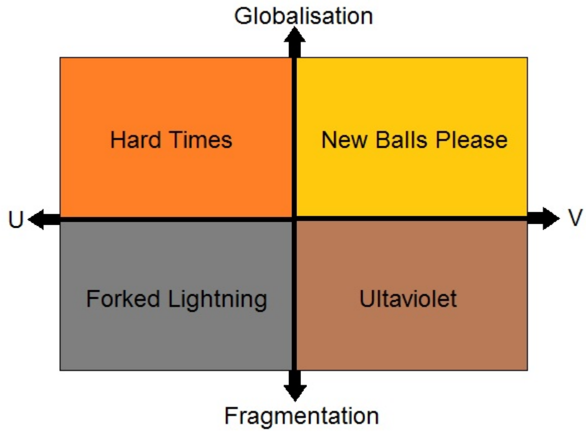


Figure B.4: Scenario Game board example.

allowing less to be borrowed to spend. The downward spiral is reinforced by plummeting commodity prices except for gold and perhaps platinum, which do well in the uncertainties around paper currencies and assets. This not an infinite state and recovery will be under way at some stage returning the world to the top right-hand quadrant.

2. The second scenario is labelled "New Balls Please" where and global effort beats the current economic hurdle but the future market is very different in its revived form, i.e. making and omelette from broken eggs. Resources will be considered limited as the East and West skirmish for economic supremacy. It is a scenario driven by the global conversion to free market economics and the continuous rise of China and India. Inflation and interest rates remain low whilst the effect of conflict zones are negated by globalisation. This scenario envisions the centre of the world economy moving East, meaning the Western institutions will have to adapt and the G8 will become the G10 with the addition of China and India as new members.

3. "Ultraviolet" is a divided world where emerging economies experience short term recovery whilst advanced economies maintain a slow growth burdened by debt. In this scenario a number of countries revert to old-style Socialist policies (South America) and become more nationalistic about the resources they possess (Russia). There will be economic momentum as the two most populous nations on earth (India and China) continue on through their industrial revolution. The emergence of more 'failed states' make investors wary whereas they would invest anywhere in the New Balls Please world state.

4. In this scenario a confluence of negative events takes place in both the political and economic arenas resulting in a repeat of the early 1930s

> when the Crash of 1932 eclipsed the Crash of 1929. Potential triggers could be an act of nuclear terrorism in a Western city, a major war in the Middle East and the consequences for US and Russian relations, or a financial meltdown in China followed by global unrest. Recovery from Forked Lightning proves slow as business confidence has to be rebuilt from nothing. Following the Crash of 1932, stocks on Wall Street only recovered pre-1929 values 20 years later.

The critical difference between "Forked Lightning" and "Hard Times" is the compromise of globalisation in the former due to political and military events. The main threats to "New Balls Please" are global warming, a growing scarcity of raw materials and the consequential rise in inflations rates or a new global health epidemic.

In the beginning of 2012, Sunter set the probability of "Ultraviolet" at 40%, making it the most probable scenario over the next 5 years at that time. One flag that would indicate a move to "Hard Times" is a dip in China's economic growth rate below 6%. Many emerging and advanced economies, such as Germany and Australia, rely on the continued success of China. Sunter gave "Hard Times" a 30% probability which is lower than "Ultraviolet" as it was the most probable alternative should China witness a decrease in economic growth as mentioned. The flags for "New Balls Please" were a decline in unemployment in the US to under 6% and a general drop in national debt to GDP ratios amongst advanced economies. Unemployment in the US is still at a historic high of around 9,5% and debt ratios continue to climb as governments have only now begun to decrease their budget deficits, resulting in a 20% probability of "New Balls Please". The principal flag for "Forked Lightning" is a rapid increase in the 10-year US Government Bond rate above 5%, indicating a loss of faith in the dollar as an reserve currency. Other flags are a default of a sovereign European state, a trade war erupting between the West and East, a destabilising conflict in the Middle East or Korea. "Forked Lightning" was assigned a 10% probability as none of the aforementioned flags were up at the time (Sunter, 2012, 14).

Flags are monitored constantly and the probabilities are adjusted as certain flags go up or down. There are other flags and scenarios excluded by the planners as they are not thought of at that exact moment, but the matrix is dynamic in itself as the axis can be replaced by new drivers as they emerge and the quadrants with new scenarios.

B.2.1 Flags

As a more specific example of the use of flags in scenario planning, a short extract from a conversation Clem Sunter had with one of his colleges, Pierre

Wack[4], in September 1989 will suffice. Pierre apparently asked Clem "Do you know that two flags have gone up on Japan which suggests its imminent demise?" Back in the 1980s, Japan was destined to be the star of the 1990s with average economic growth of 7% per annum for two decades leading up to 1990, much like the situation of modern China. Pierre answered his own question:

> *"The first flag is declining golf club membership in Tokyo. The Japanese are golf fanatics and if they are resigning from the clubs, then something is happening to their disposable income which is not captured by the media. The chances of the economy hitting the wall in the short term have gone up sharply."*
>
> *"The second flag is the demographics of Japan. It is a rich, ageing society. That does not bode well for Japan's export competitiveness; its domestic spending patterns except in the area of health care; and the amount of money that has to be set aside by the government to care for the elderly."*

The second flag multiplies the effect of the first in that it is a long term influential one, indicating that a very long financial recovery or almost flat growth rate will ensue. Three months after this specific conversation, the crash occurred and Japan's economic growth over the last 21 years has averaged 1% per annum (Sunter, 2012, 151).

B.3 Data Questionnaire Input Example

[4]Pierre Wack (1922-1997) was an oil executive who was the first to develop the use of scenario planning in the private sector, at Royal Dutch Shell's London headquarters in the 1970s. Through his scenario approach he was able to anticipate not just one Arab-induced oil shock during that decade, but two.

oil-producing facilities is well documented. Given the volumes of African oil being lost, estimated at 200 000 barrels per day (some 10% of daily production (Gambrell, 2013)) in Nigeria alone, due to unrest and conflict. Deep offshore location may offer a way around land-based vulnerabilities and represent a major step towards securing oil flows. Neglecting security can thus unleash a potential arc of conflict stretching from Sierra Leone in the west past the Ivory Coast, Nigeria and down to the Republic of Congo, DRC to Angola in the south. The volatility currently found inland will directly affect the adjacent maritime domain as it is not possible to have maritime security amidst such continental insecurity (Vrey, 2009, 92). Moreover, it is assumed that the port of Lagos will serve as support point should the SAN ever participate in sustained operations in the area.

	Level of Agreement				
	N/A	0	1	2	3
Gulf of Guinea				X	

2. *WLT*: Angola was the world's fastest-growing economy for the first 10 years of the new millennium, averaging a GDP Growth rate of 11.2 percent and reaching an all time high of 23.2 Percent in December of 2007, and it continues to be among the fastest-growing economies on the continent. Angola is Africa's second largest oil producer. As such, oil production is the main sector of the economy, accounting for about 47 percent of total GDP. The majority of Angola's oil production takes place offshore, and for the same reasons as stipulated for the Gulf of Guinea, economic activity combined within an unstable region will attract criminal activity. Given the inadequate capability of the Angolan Navy, it is not unfounded to assume that they will require support should their maritime region become unstable.

	Level of Agreement				
	N/A	0	1	2	3
WLT					X

3. *Namibian Fishing Zones*: Although the Namibian Navy has made great strides in the past decade to evolve into a organisation capable of protecting their own interests, they are not there yet. Therefore it is assumed that the SAN will still retain some of its historic responsibility in patrolling the Namibian Fishing Zones.

	Level of Agreement				
	N/A	0	1	2	3
Namibian fishing Zones					X

4. *South Africa's Economic Exclusive Zone (EEZ)*: For obvious reasons, the SAN will be required to patrol and safeguard South Africa's maritime sovereignty. The EEZ includes those territories which comprises of the areas around Marion and Prince Edward Islands.

	Level of Agreement				
	N/A	0	1	2	3
South Africa's EEZ					X

5. *Eastern Littoral Theatre (ELT)*: Operation Copper has shown that the SAN is capable and willing to take on more regional roles. Piracy in the region north of Pemba has somewhat stabilised since the inception of operation Copper but still remains a present threat.

	Level of Agreement				
	N/A	0	1	2	3
ELT					X

6. *The Strait of Hormuz*: The last potential area of operations is highly unlikely, even more so for a patrol vessel. But war is a reality and presently the Middle east is the hot spot. Should full-scale conflict erupt between Syria and Israel, drawing in Iran who consequently closes the Strait of Hormuz as promised, South Africa will stand to lose 40% of its imported oil. The SAN will be forced to take action, even if it only serves to add weight to an international effort to reopen the strait.

	Level of Agreement				
	N/A	0	1	2	3
The Strait of Hormuz		X			

Notes: Gulf of Guinea - An intelligence interest to identify security threat trends. The SAN could operate in support of UN or regional organisations. WLT - in support of SADC security ito patrols and training and to prevent possible threat migration south

HORMUZ: The SAN would find it very difficult to conduct sustained operations over a long period north of Tanzania.

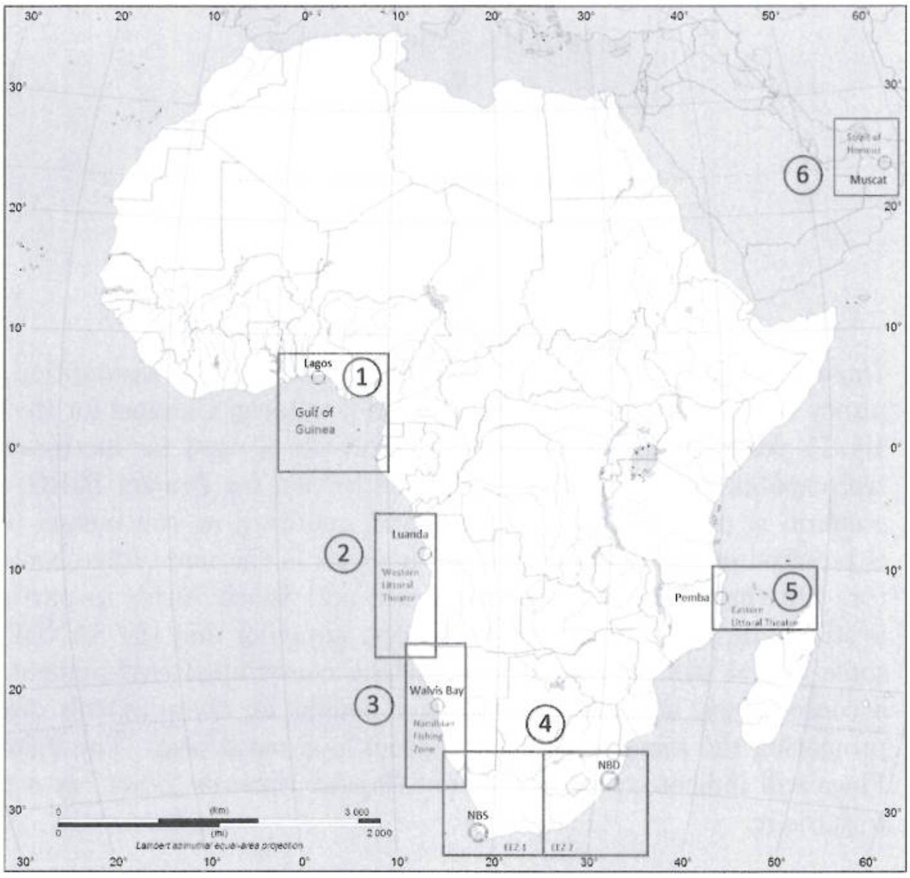


Figure B.2: Graphical presentation of demand areas

B.1.6 Scenarios

The following scenarios are based on the model developed and frequently used by Clem Sunter (2012) in building scenarios. For the more intricate workings of the model please refer to section B.2, if for anything else it makes for interesting reading. Figure B.3 displays a game-board layout of the possible future scenarios considered. The driver axes are distance and demand, both directly contributing to the transit cost of vessels. High demand is defined as a requirement for continuous patrol in the theatre.

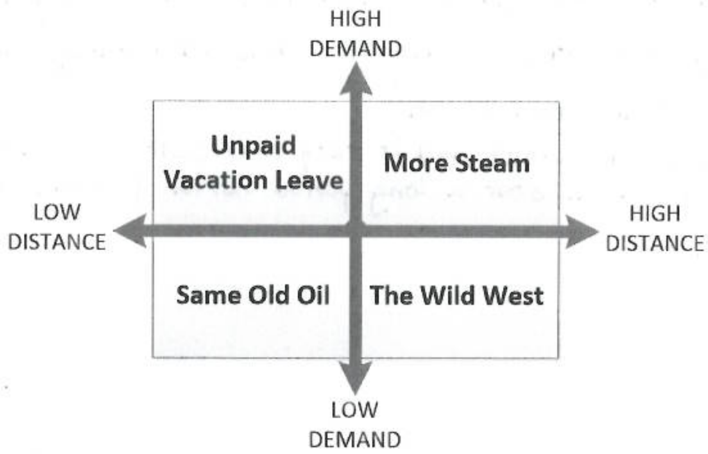


Figure B.3: Case study game-board

1. *Unpaid Vacation Leave*: This scenario is based on the assumption that piracy continues to be a threat in the Mozambican Channel for the next 10 -15 years. This persistence will motivate a need for increased patrol capability, contributing to the motivation for Project BIRO. This scenario is placed in the high demand quadrant as continuous patrol is required owing to the fact that the SAN is the main force contributor. On the economic front, the world and South Africa in particular is still enduring slow economic recovery, implying that the SANDF will some period still operate in a financially constrained environment. As a consequence, sustainable support is sought for these patrols directly promoting the reinstatement of Durban as a naval base. The following Flags will indicate continuation in "*Unpaid Vacation Leave*" or a move towards it:

   a) Continued or increased piracy related incidents in the Mozambican Channel.

   b) No increased effort from Tanzania of Mozambique to acquire adequate patrol capability.

	Level of Agreement					Scenario 1 Probability
	N/A	0	1	2	3	
Scenario 1 Flags				X		40
					X	

Comment:
05-10 years for piracy - expected to decrease
10-15 years for other criminal threats such as smuggling
Flag a) to decrease
b) Agree - even in the long term

2. *More Steam*: Scenario 2 is basically a convergence of "Unpaid Vacation Leave" and "The Wild West". In this study "More Steam" also serves as the *worst case* scenario. Criminal activity has established itself on both African coasts, leaving South Africa to split its resources between the WLT and the ELT. South Africa will have to intervene as volatility along the CSR will indirectly affect the cost of maritime trading as ships will evade docking with other counties as they sail along the African coast. Furthermore, the centre of the African economy is shifting north as trading powers no longer see South Africa as the economic key to Africa. Consequently, a popular trade route between Brazil and Nigeria emerges, redirecting critical trade from South Africa. These developments leave the SAN with no options other than to make the CSR the safest route into Africa, encouraging vessels to make South Africa their first destination. The following Flags will indicate movement towards "*More Steam*":

    a) The flags of both "Unpaid Vacation Leave" and "The Wild West".

    b) The re-emergence of the old Atlantic slave route as a viable Sea Lane of Communication (SLOC) between Brazil and Nigeria.

    c) Continued economic growth of Nigeria and Angola, with the former poised to overtake South Africa as Africa's main economy within the next 20 years, replacing South Africa on the G8 council.

	Level of Agreement					**Scenario 2 Probability**
	N/A	**0**	**1**	**2**	**3**	
Scenario 2 Flags				X		20
				X		

3. *The Wild West*: Scenario 3 sees the SAN tasked with assisting in stabilising the southern regions of the Gulf of Guinea instead of the ELT. The economic expansion of Angola has brought vast infrastructure development to their maritime domain. Unfortunately, this economic boom has exceeded the limits of the country's security capability. Consequently, a potential agreement is initiated, similar to that anchoring Operation Copper, in which the SAN provides patrol support in a operation funded by SADC or ECOWAS. The following Flags will indicate move towards "*The Wild West*":

    a) Angola's GDP growth rate continues above 8 % mark, under this growth it is likely that their security capability will keep pace.

    b) An increase in criminal activity in the region or a southwards shift of the criminal activity already present in the Gulf of Guinea

Comment for Scenario 2:

· less of a slave route than economic co-operation.
· Brazil / USA and Angola link very likely.
· both above and to ensure continued co-operation with Namibia and Angola (due to Brazilian influence) are more of a reason for SA to split resources than criminal activity.

	Level of Agreement					Scenario 3
	N/A	0	1	2	3	Probability
Scenario 3			X			10
Flags		X				

Comment: Angola more likely to increase it's maritime capability (credible) than Mozambic and Tanzania

4. *Same Old Oil*: "Same Old Oil" is a reverted state back to the days before piracy in the Mozambican Channel. Piracy in the ELT is starting to subside due to the unified pressure from regional countries, including France. There is also no signs of potential instability along the western coast of Africa. In this scenario the SAN focusses on its domestic obligations, mainline in the line of Operation Corona. Flags indicating a move towards "*Same Old Oil*":

    a) An overall decrease pirate activity along both coasts of Africa.

    b) A decrease in political will to continue with Operation Copper.

    c) The failure of BIRO to realise could put extra pressure on the SAN to relinquish regional responsibilities.

	Level of Agreement					Scenario 4
	N/A	0	1	2	3	Probability
Scenario 4				X		30
Flags					X	

Notes: Comment: piracy to decrease, especially in the ELT
. Agree with BIRO Flag - very real chance it may be either delayed or shelved.

B.1.7 Location Factors

For proper facility planning, according to Calvo and Marks (1973, 409), an explicit set of social, economic, political and environmental factors should be considered. The suitability of a specific site depends largely on the selection and evaluation of location factors. Unimportant factors, including those which are not site sensitive, should be identified and eliminated from the consideration. Location factors that have bee widely used public location research can be adapted to context of this thesis and grouped into the following main categories (Yang and Lee, 1997, 242): Economic, Environmental, Political, Social and Strategic (Table B.1).

Table B.1: Facility location factors.

		Importance			Location	
		0	1	2	SMST	DBN
1	**Economic**					
	Access to supplies / resources	X				
	Access to skilled labour	X				
	Contribution to security narrative			X	X	
	Cost of upgrading facility			X		X
	Distance to local theatres		X		X	
	Distance to regional theatres			X		X
	Dockyard efficiency			X	X	
	Economic impact on community	X				
2	**Environmental**					
	Climatic operating conditions	X				
	Governmental regulations	X				
3	**Political**					
	Co-operation with local industry			X		X
	Changing vision of organisation		X			X
4	**Social**					
	Availability of housing			X		X
	Adaptation of families			X		X
	Cost of living			X		X
	Community attitude / acceptance	X				
	Schools or Universities	X				
	Supernumerary personnel	X				
	Traditional Indian homeland		X			X
5	**Strategic**					
	Air-force support	X				
	Fully independent support ability		X		X	
	Prevent deterioration of NSD	X				
	Protecting key-point harbours		X			X
	Second base			X		X

		Rank
1	Economic	3
2	Environmental	5
3	Political	2
4	Social	4
5	Strategic	1

Notes: NBD will not be capable of, or is it desirable that it should, be capable to do what NB SMST can do. (eg dry dock dedicated to Navy etc) It will provide diversification and strengthen the SAN's capability to operate in the ELT - which is politically desirable.

B.2 Scenario Crafting

Chantell Ilbury and Clem Sunter[3] have developed a scenario planning technique that presents different scenarios in a matrix, rather than listing them individually. This allows the logical connection between the scenarios to be more easily visualised. The choice of the two axis that form the matrix is crucial, these should be the real driving forces for each scenario. The other modifications they have made to the scenario process are to identify "flags" which indicate movement towards one specific scenario (quadrant); and then, attach a subjective probability to each scenario based on the tendencies of the flags. The flags are constantly monitored to determine the state of the matrix and to adjust the probabilities of all scenarios as soon as a flag is raised.

To better explain both the matrix method and the concept of flags, a scenario developed by Sunter (2012) will be used as an example throughout this section. He named this specific scenario matrix "The global tightrope", which illustrates four possible scenarios (Figure B.4) likely to unfold, according to the various drivers and flags, following the 2008 financial crash. Firstly, the two axis (drivers). The horizontal axis describes the rate of economic recovery as a driver with U denoting a slow and V denoting a quick economic recovery.

[3]Mr. Sunter was awarded an Honorary Doctorate by the University of Cape Town for his work in the field of scenario planning. He was also voted by leading South African CEOs as the speaker who has made the most significant contribution to, and impact on, best practice and business in South Africa. In 2006, he was invited to give a scenario presentation at the Central Party School in Beijing - a rare privilege for a foreigner.

B.4 Fuzzy Logic

The initial development of fuzzy set theory was motivated by the perception that traditional techniques are not effective in solving problems in which the variables are too complex or ill-defined to allow accurate and precise calculation. Such problems are the norm in biology, psychology, economics, linguistics and many other fields (Bojadziev and Bojadziev, 1997).

A common factor in these types of problems is the inherit imprecision, uncertainty and partiality of truth when defining goals and boundaries. The concept of a fuzzy set is a more accurate reflection of this reality. Bojadziev and Bojadziev (1997) states that fuzzy sets, "serves as a point of departure for the development of theories which have the capability to model the pervasive imprecision and uncertainty of the real world."

As mentioned, traditional or classical modelling techniques often do not reflect the nature of complex systems, especially when human inputs are involved. In contrast, fuzzy sets and fuzzy logic have proven to be effective tools for modelling in the absence of complete or precise information. When faced with inexact data, the subjective judgement of experts lead by fuzzy logic techniques have produced better results than the objective manipulation of the data set (Bojadziev and Bojadziev, 1997).

To summarise, fuzzy logic stems from the inability of classic logic to capture the data in natural language, common sense reasoning, and problem solving heuristic used by people every day. Fuzzy logic provides a methodology for dealing with linguistic variables and describing modifiers like, close, very, fairly, not, etc. Bojadziev and Bojadziev (1997) states it perfectly, "fuzzy logic deals with objects that are a matter of degree, with all possible grades of truth between 'yes' and 'no.' It can be viewed as a broad conceptual framework encompassing the classical logic which divides the world on the basis of 'yes' and 'no."'

B.4.1 The classical set

The classical set will be explained or revised through an example from Bojadziev and Bojadziev (1997, 8) using a crisp set to describe *tall men.* Consider for instance a man is tall if his height is 180 cm or greater; otherwise the man is not tall. The characteristic function of the set A = {tall men} then is

$$\mu_A(x) = \begin{cases} 1 & \text{for} \quad 180 \leq x \\ 0 & \text{for} \quad 160 \leq x < 180 \end{cases}$$

Figure B.5 illustrates the set in universe U=$\{x|160\leq x<180\}$.

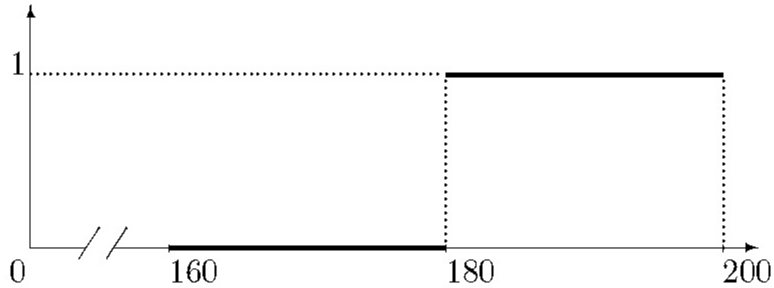


Figure B.5: Membership function of the set *tall men*

Clearly this description of *tall men* is not satisfactory. According to the model a person who is 179 cm is not tall in conjunction with a person whose height is 150 cm. Yet a person of 180 cm is tall as well as a person with height 200 cm. The vague definition of the word *tall* contributes to the problem being an illogical fit to the black or white model of the classical set, which fails to describe realistic borderline cases.

B.4.2 Definition of fuzzy sets

In the classical set a object is either a member to a set or it is not, consequently the function can only take two values, 1 or 0. The previous example illustrates the need to increase the describing capabilities of sets while dealing with words or linguistic variables as they will be referred to henceforth.

Assume now that a characteristic function may take values in the interval [0,1]. The concept of membership is no longer *crisp*, but becomes *fuzzy* in the sense of partial belonging or *degree of membership.*

A *fuzzy* set $\mathcal{A}$ is then defined as,

$$\mathcal{A} = \{(x, \mu_{\mathcal{A}}(x))|x \in A, \mu_{\mathcal{A}}(x) \in [0,1]\}, \tag{B.1}$$

where $\mu_{\mathcal{A}}(x)$ is a function called *membership function*; $\mu_{\mathcal{A}}(x)$ specifies the *degree* to which any element in A belongs to the fuzzy set $\mathcal{A}$. Larger values of $\mu_{\mathcal{A}}(x)$ indicate higher degrees of membership, or "closer to the truth". Let us refer to the example of the tall men; if a person has a membership of 0.7, it can be said that he is 70% tall. The notion of fuzzy sets is sometimes incorrectly confused with probability, thus it cannot be said that there is a probability of 78% that he is tall. The following characteristics will apply to *fuzzy* sets throughout this section as defined by Bojadziev and Bojadziev (1997, 10-11) :

· *Fuzzy* sets are denoted by italic letters $\mathcal{A}$, $\mathcal{B}$, $\mathcal{C}$, . . . , and the corresponding membership functions by $\mu_{\mathcal{A}}(x)$, $\mu_{\mathcal{B}}(x)$, $\mu_{\mathcal{C}}(x)$, ...

· A *fuzzy* set is *normalised* when at least one $x \in A$ attains the maximum membership grade of 1; otherwise a set is called *non-normalised*.

· Assume a set $\mathcal{A}$ is non-normalised; then max $\mu_{\mathcal{A}}(x) < 1$. To normalise set $\mathcal{A}$ means to normalise its membership function $\mu_{\mathcal{A}}(x)$ by dividing it by the maximum $\mu_{\mathcal{A}}(x)$, which gives $\frac{\mu_{\mathcal{A}}(x)}{max\mu_{\mathcal{A}}(x)}$.

To summarise membership in the definition of *fuzzy* sets, let us assign the following values on [0, 1] to the membership function $\mu_{\mathcal{A}}(x)$ of $\mathcal{A}$:

$$\mu_{\mathcal{A}}(x_1) = 0.1, \quad \mu_{\mathcal{A}}(x_2) = 0.5, \quad \mu_{\mathcal{A}}(x_3) = 0.3,$$
$$\mu_{\mathcal{A}}(x_4) = 0.8, \quad \mu_{\mathcal{A}}(x_5) = 1, \quad \mu_{\mathcal{A}}(x_6) = 0.2.$$

The element x_5 is a *full* member of the *fuzzy* set $\mathcal{A}$, while element x_4 is *almost* or *close* to a full member of $\mathcal{A}$. Element x_1 is a member of $\mathcal{A}$ a *little* (near 0); x_6 and x_3 are a *little more* members of $\mathcal{A}$, while x_2 is *more or less* a member of $\mathcal{A}$. These terms will become clearer as the utilisation of fuzzy logic is discussed.

B.4.3 Triangular Fuzzy Numbers

A *Triangular fuzzy number A* or shortly triangular number, are often used in the following applications according to Bojadziev and Bojadziev (1997, 22); fuzzy controllers, managerial decision making, business and finance, social sciences, etc. A triangular number with membership function $\mu_{\mathcal{A}}(x)$ is defined by

$$\mu_A(x) = \begin{cases} \frac{x-a_1}{a_M-a_1} & \text{for} \quad a_1 \leq x \leq a_M \\ \frac{x-a_2}{a_M-a_2} & \text{for} \quad a_M \leq x \leq a_2 \\ 0 & \text{otherwise} \end{cases}$$

where $[a_1, a_2]$ is the supporting interval and the point $(a_M, 1)$ is the peak as seen in Figure B.6.

Assume a problem has an certain unknown variable, but the maximum and minimum values of this value can be specified, i.e. the interval $A = [a_1, a_2]$. If a plausible value a_M can be indicated on the interval, it will represent the point $(a_M, 1)$. Consequently, with the three values a_1, a_2 and a_M, a triangular member can be constructed and its membership function can be defined, and denoted by

$$A = (a_1, a_M, a_2)$$

Mentioned above are just the basic notations used in triangular fuzzy numbers. The application of this method will be discussed and demonstrated in the following sections.

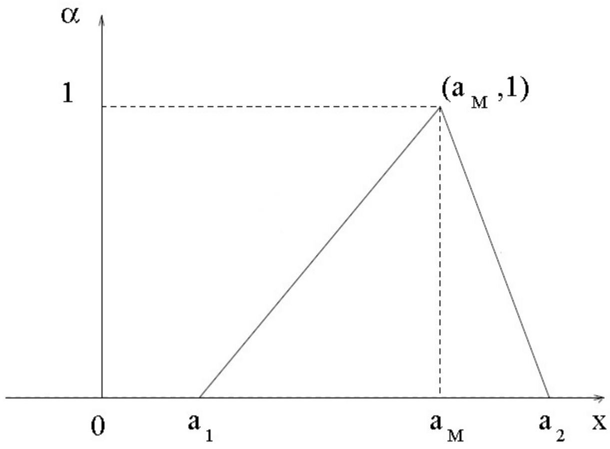


Figure B.6: Triangular fuzzy number

B.4.4 Trapezoidal Fuzzy Numbers

A *trapezoidal fuzzy number* A or simply trapezoidal number, are especially suitable to represent the linguistic variables *small* and *large*, (Bojadziev and Bojadziev, 1997, 24). A trapezoidal number with membership function $\mu_{\mathcal{A}}(x)$ is defined by

$$\mu_A(x) = \begin{cases} \frac{x-a_1}{b_1-a_1} & \text{for} & a_1 \leq x \leq b_1 \\ 1 & \text{for} & b_1 \leq x \leq b_2 \\ \frac{x-a_2}{b_2-a_2} & \text{for} & b_2 \leq x \leq a_2 \\ 0 & \text{otherwise} & \end{cases}$$

The supporting interval is $A = [a_1,\, a_2]$ and the flat segment on level $\alpha=$ 1 has projection $[b_1,\, b_2]$ on the x axis. With these four values the trapezoidal number (Figure B.7) can be denoted by

$$A = (a_1, b_1, b_2, a_2)$$

If $b_1 = b_2 = a_M$, the trapezoidal number represents a triangular fuzzy number and is denoted by

$$A = (a_1, a_M, a_M, a_2) = (a_1, a_M, a_2) \qquad \text{(B.2)}$$

Once again this is to define the basic elements of fuzzy logic in the decision making process that will be explained in sequent chapters culminating in Section B.4.6.

B.4.5 Linguistic Modifiers

Let $x \in$ and $\mathcal{A}$ be a *fuzzy* set with membership function $\mu_{\mathcal{A}}(x)$. Assume a *linguistic modifier* is denoted by m, for instance *very*, *not*, *fairly* (more or

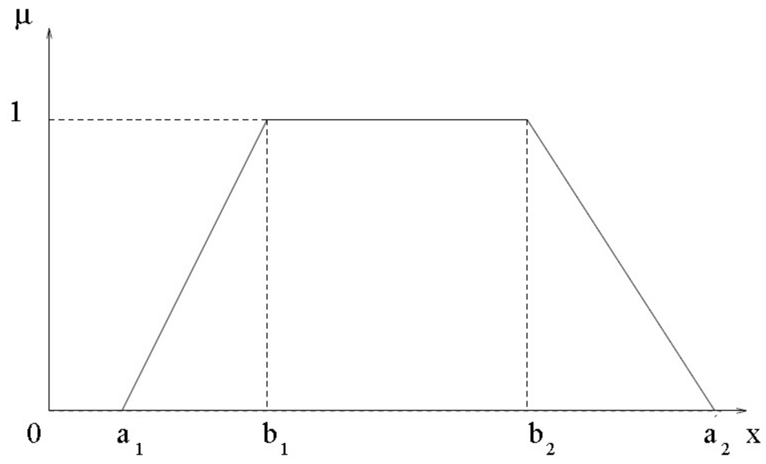


Figure B.7: Trapezoidal fuzzy number.

less), etc. Then $m\mathcal{A}$ represents a modified fuzzy set by m with membership function $\mu_m\mathcal{A}(x)$. Bojadziev and Bojadziev (1997, 46) uses the following to describe modifiers, *not*, *very* and *fairly*:

$$\text{not,} \quad \mu_{not}\mathcal{A}(x) = 1 - \mu_{\mathcal{A}}(x) \tag{B.3}$$

$$\text{very,} \quad \mu_{very}\mathcal{A}(x) = [\mu_{\mathcal{A}}(x)]^2 \tag{B.4}$$

$$\text{fairly,} \quad \mu_{fairly}\mathcal{A}(x) = [\mu_{\mathcal{A}}(x)]^{1/2} \tag{B.5}$$

A modified example from Bojadziev and Bojadziev will be used to demonstrate the use of linguistic modifiers. Consider the *fuzzy* set $\mathcal{A}$ describing the linguistic variable *high score* related to a scoring model defined as

x	0	20	40	60	80	100
$\mu_{high}(x)$	0	0.2	0.5	0.8	0.9	1

where x is the base variable over universal set $U_1 = \{0, 20, 40, 60, 80, 100\}$.The linguistic value *high score* can be modified to become *not high score*, *very high score* and *fairly high score*by using equations (B.3) - (B.5). We will find *not high score*, *very high score* and *fairly high score* in that order by constructing modified versions of the *high score* table. Using the table for $\mu_{high}(x)$ the following is calculated as an example:

$$\mu_{nothigh}(x) = 1 - \mu_{high}(80) = 1 - 0.9 = 0.1$$

Hence by repeating the above calculation for all values of $\mu_{high}(x)$ the following table can be obtained for the fuzzy set *not high score*

x	0	20	40	60	80	100
$\mu_{nothigh}(x)$	1	0.8	0.5	0.2	0.1	1

Similarly the tables for the *fuzzy* sets *very high score* and *fairly high score* can be constructed

$$\mu_{veryhigh}(x) = [\mu_{high}(x)]^2$$

x	0	20	40	60	80	100
$\mu_{veryhigh}(x)$	0	0.04	0.25	0.64	0.81	1

$$\mu_{fairlyhigh}(x) = [\mu_{high}(x)]^{1/2}$$

x	0	20	40	60	80	100
$\mu_{fairlyhigh}(x)$	0	0.447	0.707	0.894	0.949	1

It is evident from these formulations that we can mathematically find membership values for extensions on already subjective variables of say; *poor*, *fair* and *good*. An example pertaining to the above would be to ask three students who all scored the same how they score themselves. The first would answer that she/he is 90% sure they scored a high mark, the next one would state that she/he is 80% sure they did very well (read very high) and the last person would state she/he is 95% certain that they did fairly well (read fairly high). Although all the above students scored the same, they were given a framework in which they could comfortably express their scores linguistically.

B.4.6 Decision Making in a Fuzzy Environment

Decision making plays an important role in every professional environment, be it in management, business, finance, economics, social and political science, engineering and computer science, biology, and medicine (Bojadziev and Bojadziev, 1997, 91). It is a difficult process due to the increasing complexity of problems in a more subjective, incomplete and imprecise environment, which tend to represent real-life situations to a greater degree, i.e. a fuzzy environment. The objective of this chapter is to introduce two different decision making methods which apply the triangular and trapezoidal fuzzy numbers discussed in Sections B.4.3 and B.4.4. First of the two methods is the Bellman and Zadeh (1970) approach, which defines decision making as an intersection of goals and constraints described by *fuzzy* sets. The second approach combines goals and constraints and averages the result, also known as fuzzy averaging Bojadziev and Bojadziev (1997, 91). Both methods will be explained through the use of real-life models as examples.

B.4.7 Intersection of Fuzzy goals and Constraints

The decision making process basically consists of reaching goals while keeping to certain constraints. Within these parameters a set of alternatives are found or discovered. A simple decision-making model will serve as example,consisting of a goal described by a *fuzzy* set $\mathcal{G}$ with membership function $\mu_{\mathcal{G}}(x)$ and a *fuzzy* set $\mathcal{C}$ with membership function $\mu_{\mathcal{C}}(x)$ describing constraints. The product of this model is a crisp set of alternatives A_{alt} of which x is a element and x_{max} the best decision or alternative.

By definition (Bellman and Zadeh (1970)) the decision is a *fuzzy* set $\mathcal{D}$ with membership function $\mu_{\mathcal{D}}(x)$, expressed as an intersection (denoted by $\mathcal{G} \cap \mathcal{C}$) of goals ($\mu_{\mathcal{G}}(x)$) and constraints ($\mu_{\mathcal{C}}(x)$),

$$\mathcal{D} = \mathcal{G} \cap \mathcal{C} = \{x, \mu_{\mathcal{D}}(x) | x \in [d_1, d_2], \quad \mu_{\mathcal{D}}(x) \in [0, h \leq 1]\}. \tag{B.6}$$

$$\mu_{\mathcal{G} \cap \mathcal{C}} = \min(\mu_{\mathcal{G}}(x), \mu_{\mathcal{C}}(x)) \quad x \in U. \tag{B.7}$$

A schematic presentation is shown on Figure B.8, where the decision resulted in a crisp set $[d_1,d_2]$; $\mu_{\mathcal{D}}(x)$ indicates the grade or degree to which any $x \in [d_1,d_2]$ belongs to decision $\mathcal{D}$, derived from using the membership functions and intersection operations (B.7). Formula (B.6) then produces

$$\mu_{\mathcal{D}}(x) = \min(\mu_{\mathcal{G}}(x), \mu_{\mathcal{C}}(x)) \quad x \in U. \tag{B.8}$$

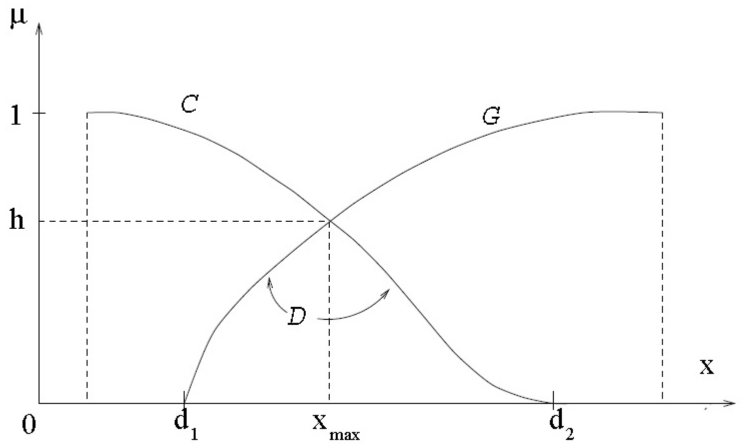


Figure B.8: Fuzzy goal $\mathcal{G}$, constraint $\mathcal{C}$, decision $\mathcal{D}$ and max decision x_{max}

Now that the decision set $\mathcal{D}$ has been defined, a value x can be selected with the highest degree of membership in the set $\mathcal{D}$. Such a value x maximises

$\mu_{\mathcal{D}}(x)$ and is called the *maximising decision*(Bojadziev and Bojadziev, 1997, 93) (Figure B.8)

$$x_{max} = \{x|\max\mu_{\mathcal{D}}(x) = \max\ \min(\mu_{\mathcal{G}}(x), \mu_{\mathcal{C}}(x))\}. \qquad \text{(B.9)}$$

A pricing model, modified from Bojadziev and Bojadziev (1997, 104), will be used to demonstrate the application of the Intersection approach. Consider a pricing model consisting of three requirements, be they either goals or constraints:

$\mathcal{R}_1$ = The product should have a *low price*;

$\mathcal{R}_2$ = The product should have a *price close to double manufacturing cost*;

$\mathcal{R}_3$ = The product should have a *price close to competition price*;

Assume that the lowest price considered for the product is 10, the competition price is 25 and the manufacturing cost is 15. The set of alternatives A_{alt} is the interval [10,50], meaning that the price should be selected from this interval.

The model is shown in on Figure B.9. The linguistic values are described by fuzzy numbers, i.e. $\mathcal{R}_1$ is represented by triangular number A_1 (*low price*), $\mathcal{R}_2$ and $\mathcal{R}_3$ are represented by triangular numbers A_2 (*price close to competition price*) and A_3 (*price close to double manufacturing cost*) respectively. The membership functions correspond as follows:

$$A_1 = \mu_{A_1}(x) = \begin{cases} \frac{-x+40}{30} & \text{for} \quad 10 \le x \le 40, \\ 0 & \text{otherwise,} \end{cases}$$

$$A_2 = \mu_{A_2}(x) = \begin{cases} \frac{x-20}{5} & \text{for} \quad 20 \le x \le 25, \\ \frac{-x+30}{5} & \text{for} \quad 25 \le x \le 30, \\ 0 & \text{otherwise,} \end{cases}$$

$$A_3 = \mu_{A_3}(x) = \begin{cases} \frac{x-25}{5} & \text{for} \quad 25 \le x \le 30, \\ \frac{-x+35}{5} & \text{for} \quad 30 \le x \le 35, \\ 0 & \text{otherwise,} \end{cases}$$

The decision set $\mathcal{D}$ (Figure B.9) is in the interval [25, 30] from (B.8),

$$\mu_{\mathcal{D}}(x) = \min(\mu_{A_1}(x), \mu_{A_2}(x), \mu_{A_3}(x)).$$

Solving $\mu = \frac{-x+40}{30}$ (A_1) and $\mu = \frac{x-25}{5}$ (A_3) gives the maximising decision as seen in Figure B.9 with $x_{max} = 27.14$. This will be a recommendation to the DM. Note that triangular number A_2 (*price close to competition price*) had no influence on the decision x_{max}. This concludes decision making by intersection of fuzzy goals and constraints. The example will be repeated and results compared in the next section.

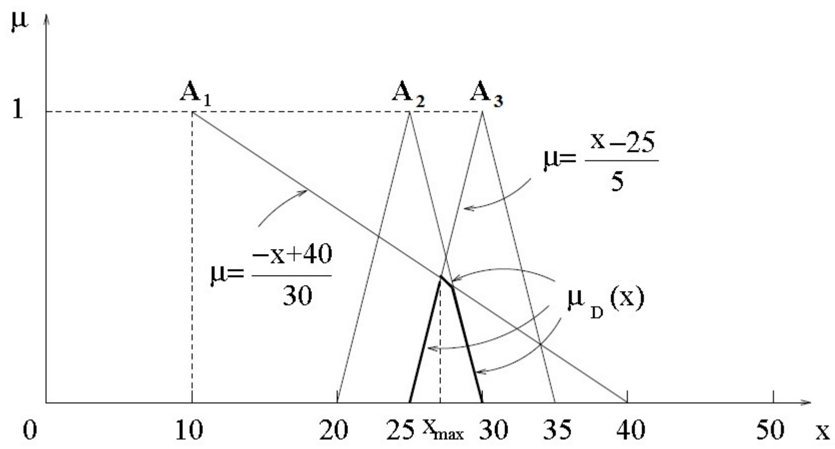


Figure B.9: Intersecting pricing model with requirements $\mathcal{R}_1$, $\mathcal{R}_2$ and $\mathcal{R}_3$

B.4.8 Fuzzy Averaging for Decision Making

In this section the fuzzy averaging technique as a tool for decision making will be briefly discussed. The statistical average of the goals $\mathcal{G}$ and constraints $\mathcal{C}$ will be used to define the decision number $\mathcal{D}$.

If $A_i = (a_1^{(i)}, b_1^{(i)}, a_2^{(i)}, a_2^{(i)})$, $i = 1, \ldots, n$, are trapezoidal numbers,the average formula will then be

$$\begin{aligned} A_{ave} &= \frac{(a_1^{(1)}, b_1^{(1)}, a_2^{(1)}, a_2^{(1)}) + \cdots + (a_1^{(n)}, b_1^{(n)}, a_2^{(n)}, a_2^{(n)})}{n} \\ &= \frac{(\sum_{i=1}^n a_1^{(i)}, \sum_{i=1}^n b_1^{(i)}, \sum_{i=1}^n b_2^{(i)}, \sum_{i=1}^n a_2^{(i)})}{n}. \end{aligned} \quad \text{(B.10)}$$

In the case of a triangular number, $b_1 = b_2$ and thus b_2 falls out of the equation, as in the next example. The maximising decision will be the value on the supporting interval of $\mathcal{D}$ for which $\mu_{\mathcal{D}}(x)$ has a membership degree of one. Consider the model used in the intersection example and presented on Figure B.9. The requirements $\mathcal{R}_1$, $\mathcal{R}_2$ and $\mathcal{R}_3$ are described by triangular numbers which can be written in the form

$$A_1 = (10, 10, 40) \qquad A_2 = (20, 25, 30) \qquad A_3 = (25, 30, 35),$$

Using the trapezoidal average formula (B.10) one gets the decision

$$\begin{aligned} D = A_{ave} &= \frac{A_1 + A_2 + A_3}{3} \\ &= \frac{(10, 10, 40) + (20, 25, 30) + (25, 30, 35)}{3} \end{aligned}$$

$$= \frac{(55, 65, 105)}{3}$$

$$= (18.33, 21.67, 35)$$

It is the triangular number D shown in Figure B.10. The maximising decision is $x_{max} = 21.67$ since at this value the membership function $\mu_D(x)$ is one. The maximum decision for the intersecting model is 27.14. There is a significant difference between the two decisions.

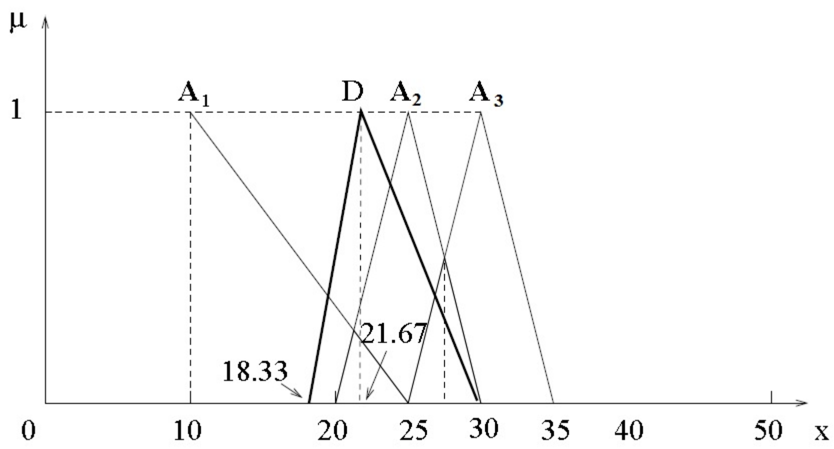


Figure B.10: Averaging pricing model with requirements $\mathcal{R}_1$, $\mathcal{R}_2$ and $\mathcal{R}_3$

Which one is correct? Both decisions should be considered as suggestions. The value 27.14 does not reflect the competition price A_2. Then again, 21.67 is very close too manufacturing cost and does not reflect the double profit requirement A_3 although it is influenced by it. A compromise could be to average the intersection (27.14) and averaging (21.67) numbers, which is 24.4. Once again it serves to emphasise that this number should serve as a suggestion to the DM. It is worthy to note that only the peaks of the triangles have an effect on the averaging decision. If A_1 were to change to new $A_1 = (10, 10, 25)$ it would still have the same peak as the old A_1. The result from (B.10) would be $A_{ave} = (18.33, 21.67, 30)$, hence $x_{max} = 21.67$ would still be the same as in the previous model.

B.4.9 Multi-Expert Decision Making

To conclude the use of fuzzy logic in decision making, the contribution of fuzzy logic in the combining of opinions from multiple experts, will be briefly discussed. The solving of complex problems requires the involvement of many experts. Consequently, varying or conflicting opinions are expressed as linguistic values, thus ideal to be described and processed by fuzzy logic, which can be used to combine these opinions to produce one decision. Bojadziev and Bojadziev (1997, 115) calls this multi-expert decision making procedure *aggregation*; a resolution of conflicting opinions. Aggregation is obtained by applying fuzzy averaging (Section B.4.8). Accordingly a modified approach is necessary when experts are ranked or have different importance.

To demonstrate a modified method, consider as an example a simplified individual investment planning model that produces an *aggressive* or *conservative* policy depending on the movement of interest rates. Let us assume the financial experts have conflicting opinions on what action should be taken when interest rates are falling. This means some experts are recommending an *aggressive* policy (scale from 0 to 100) while others are recommending an opposite, *conservative* policy (scale from -100 to 0); let us also assume there is a possibility that some experts may express opinions in the middle of the spectrum, between *aggressive* and *conservative* policy. Suppose the three experts present their opinions on the matter by the fuzzy numbers (see Figure B.11):

A_1 = (-100,-100,-50,-30), *conservative*, trapezoidal number,

A_2 = (-10,10,30),*slightly aggresive*, triangular number,

A_3 = (60,90,100,100),*aggresive*, trapezoidal number;

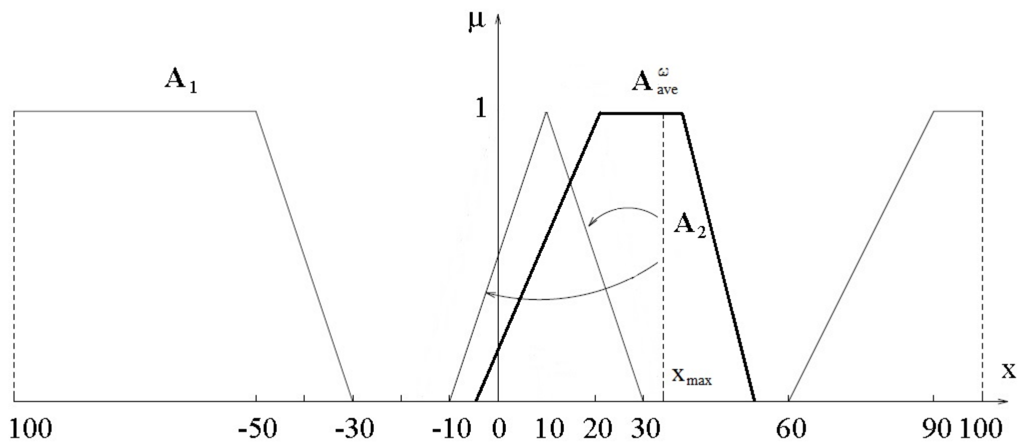


Figure B.11: Averaging conflicting experts' opinions.

To use aggregation of the three conflicting opinions, A_2 must first be presented as a trapezoidal number. A_2 can be expressed as trapezoidal number, A_2 = (-10, 10, 10, 30). Add to this model the varying importance of each expert, e.g. on a scale of 0 to 10. The ranking of expert E_1,E_2 and E_3 is assumed to be 5, 5 and 10 respectively. The weights w_i for E_i are accordingly

$$w_i = \frac{\lambda i}{\lambda_1 + \lambda_2 + \lambda_3};\ w_1 = \frac{5}{20} = 0.25;\ w_2 = \frac{5}{20} = 0.25;\ w_3 = \frac{10}{20} = 0.5$$

Using (B.10) to aggragate the conflicting expert opinions gives

$$\begin{aligned} A^w_{ave} &= 0.25A_1 + 0.25A_2 + 0.5A_3 \\ &= (-25, -25, -12.5, -7.5) + (-2.5, 2.5, 2.5, 7.5) + (30, 45, 50, 50) \\ &= (2.5, 22.5, 43, 50) \end{aligned}$$

whose maximising value (Figure B.11) is $x_{max} = \frac{22.5+43}{2} = 32.75$, indicating that the policy should be cautiously aggressive. The recommended policy is due to the highest ranking expert favouring an aggressive investment policy.

Appendix C

Essential Concepts

C.1 The Asymmetrical Threat

Asymmetric warfare have been around for virtually as long as mankind has, although not necessarily termed or conceptualised as such. Military forces have always attempted to seek some advantage so as to inflict maximum damage at minimum cost, especially to offset any conventional superiority the opponent may have. Today states face terror, suicide bombers and improvised incendiary devices. Assets such as light aircraft, helicopters, airliners, high speed boats or luxury yachts can be utilised to leverage terror, economic or political exploitation. A threat is asymmetric if it contains the following three elements, the first being the general definition of a threat (Hugo, 2009, 104):

The threat must involve a weapon, tactic or strategy that a state or non-state entity (the antagonist) both could and would employ against another entity (the protagonist). It is worthy to note that if you do not posses the ability to absolutely confirm the threat it probably indicates that you do not have the capability to neutralise it. In such cases the treats should be taken seriously, real or false, or run the risk of the enemy capitalising on the vulnerability. An example would be the threat of enemy mines at a port, entrance or approach to an particular port. If the protagonist entity does not posses the means to detect the mines, he will probably not posses the capability to neutralise it. Ignoring the threat will bring about the risk of the possible sinking of a vessel and the consequential closing of that area. Adding to the obvious scenario, the sinking of a vessel by a mine would confirm the presence of the mines but of course also offers unorthodox means to neutralise the threat. This serves to introduce the next element.

The threat must involve a weapon, tactic or strategy that the protagonist state or entity would not employ. Alternatively put, it is a weapon, tactic or strategy that the protagonist entity would not combat by retaliating in kind, therefore, failing to deter by threatening to retaliate in kind. An example would be "the buccaneers" of the 17^{th} and 18^{th} centuries, where the brutal reputation of the pirates helped them achieve victories over superior enemies. Conventional naval forces of that era could, for obvious reasons, not retaliate in kind. Another maritime example would be the Japanese use of kamikaze attacks during the latter part of World War II. These weapons, essentially what they were after disregarding the human factor and the cost of the pilot's life, were relatively cheap and hit approximately 400 ships off Okinawa island. Once again, to retaliate in kind was not an option for the Allied forces, therefore they could not effectively deter the kamikaze threat.

Lastly, the threat must involve a weapon, tactic or strategy that, if not countered, could have serious consequences and is a weapon, tactic or strategy that is not already countered by symmetrical systems.

Simply put, the difference between symmetric and asymmetric warfare or tactics can be illustrated by the game dynamics of chess without going into needless detail. In symmetrical warfare, both sides have the same pieces, if the antagonist moves a piece, the protagonist moves the same piece or a more appropriate piece to counter the threat, the main advantages being the position and quantity of the pieces. If one player would use a knight to take one of the opponent's pieces by jumping over another piece that would otherwise have provided sufficient protection, it would be move characterised by asymmetrical tactics. In its most extreme form, asymmetrical warfare would consist of a chess board where one side consists of flexible and powerful pieces (the whole backorder minus the King) whilst the other only has pawns. Barring the amount of moves needed, the strength and vulnerability of the side with only pawns will be inversely proportional to its flexibility. A diagonal pawn chain where each pawn protects the other, as long as they remain in that order, is strong but stationary. Such a structure, irrelevant of its rigidity, coverage or complexity, cannot counter the asymmetrical threat of rooks, bishops or knights to their anchor pawns (read serious consequences).

Good intelligence should be the backbone of any real counter of an asymmetrical threat. The protagonist has to assess the objective of the antagonist as best as possible. Is it their objective to shut down a port or to kidnap millionaires of their luxury yachts? Both serious threats but to be countered differently.

For warships the odds presented by asymmetric threat are not much lower, although they are by definition more capable of self-defence. The physiological and political impact of losing a ship has historically been much greater, bearing in mind that warships of a sovereign are considered to be part of the sovereign's territory while they are at sea. The German battleship *Deutschland* was renamed by Hitler as the psychological consequences of the loss of such a major battleship carrying such a prestigious name was too terrible to contemplate. The US Navy have on numerous occasions referred to their aircraft carriers as "a piece of America", making them attractive targets for parties who want to physically damage or destroy "a piece of America". To emphasise this point, the terrorist attack on the *USS Cole* and the subsequent damage led to an intense image-damage-control by the United States. National prestige was at stake (Hugo, 2009, 109).

The question here is if South Africa can afford to lose one of its warships to an asymmetrical threat. The cost of such an incident should be weighed up against the cost of outsourcing or partnering with private security companies.

C.2 Littoral Zone

Simply put, the Littoral Zone is the part of the sea close to the shore. In a more specific, military related sense, the Littoral Zone is viewed as the Coastal Area (Coast, Beach and Near-shore) plus an offshore area until the depth reaches about 60m. A comprehensive illustration is provided in the Appendix.

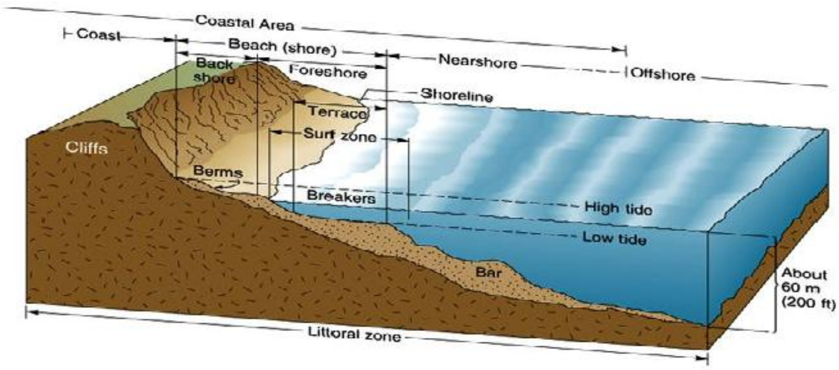


Figure C.1: Littoral Zone Def

C.3 Syncrolift®

A Syncrolift® system is simply a large elevator which raises and lowers vessels in and out of the water for dry-docking ashore.

To dock a vessel, the platform and cradle are lowered into the water, and the vessel moved into place over the platform (Figure C.2). When in position, the platform is raised, removing the vessel from the water. The vessel can then transferred ashore, leaving the Syncrolift available to dock other vessels (Figure C.3). On completion, the process is reversed.

Figure C.2: Daphné class submarine moved onto lift.

Figure C.3: Warrior class OPV transferred from lift.

C.4 Strait of Hormuz

Twenty percent of oil traded worldwide moves by tanker through the Strait of Hormuz, the world's most important petroleum transit choke point. In 2011, Saudi Arabia led six Persian Gulf nations in exporting 16 million barrels per day of crude oil through the 2-mile-wide (3.2-kilometer-wide) shipping lane.

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