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Review of Transnet National Ports Marine Concrete Infrastructure Asset Management and Maintenance

Minor Dissertation – CIV5017Z
By

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Date: November 2019

DECLARATION BY CANDIDATE

Benedict Isaacs hereby declares that:

- This study has not been submitted before and is not being concurrently submitted for another degree.
- The submission of this dissertation is in partial fulfilment of the requirements for the Master of Engineering Civil Infrastructure Management and Maintenance degree.
- This dissertation results from my research work and investigation, except where otherwise stated and referenced.
- The sources of information used in this research are acknowledged by referencing. A complete list of references is attached to this dissertation.

SIGNATURE: Signed by candidate

DATE:

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ABSTRACT

The South African Ports are considered a key engine for the economic growth of the country for import and export trade as well as passenger ships. In order to provide such services, the ports' waterside / wet concrete assets are pivotal to the business as trade and travel are reliant on the availability of safe and well-maintained concrete assets.

Transnet is a State-Owned Company (SOC), wholly owned by the Government of the Republic of South Africa and is the custodian of rail, ports, and pipelines. The asset management and maintenance of Transnet's infrastructure assets are, therefore, the cornerstone of delivering on their mandate as a SOC. Moreover, to deliver on their mandate, systematic, holistic, and integrated approaches to asset management and maintenance of their assets are imperative. This dissertation focuses on the Transnet National Ports Authority (TNPA) division. It has a very large asset base of Infrastructure, in particular its marine concrete infrastructure. Regulated by the National Ports Act 2005 (Act No. 12 of 2005), some of their core functions are the planning, provision, maintenance, and improvement of port infrastructure. This dissertation gives a background on the structure of the South African Ports and operations and the types and age of concrete structures within the ports. The study also critically assesses the existence of and the type of Infrastructure Asset Management & Maintenance (IAMM) systems currently in place for the Asset Management and Maintenance of TNPA's concrete infrastructure assets. The approach and methods of managing and assessing assets' condition and maintaining their existing concrete structures are reviewed to ascertain whether their asset management systems are aligned and conform to certain IAMM standards, codes, and guidelines. The Asset Maintenance Principles & Procedures (AMPP) document is also reviewed for its effectiveness in maintaining assets. In order to get a holistic idea of the extent of the possible shortcomings of TNPA's current maintenance and asset management strategies, other ports around the world with similar or the same concrete infrastructure are identified and assessed for commonalities and deviations from best practices. The research methodology used is qualitative using the analysis of existing text and literature as well as case studies of other ports as a source of data.The findings of the research show that although there are good maintenance systems and guidelines in place with some elements of asset management principles, an all encompassing civil infrastructure asset management framework for the marine concrete assets does not exists where the benefits of a properly implemented asset management framework can be realised. The research also shows that asset management is largely treated as a financial exercise with finance being the custodian of asset management. Recommendations are made for dealing with the shortcomings identified. Recommendations are also made for a more in-depth case study for the TNPA to conduct based on the findings of this dissertation.

Keywords: (Infrastructure Asset Management, Maintenance, Transnet, TNPA, AMPP, concrete structures, standards, systems, ISO standards)

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LIST OF ABBREVIATIONS

1. AIA: Approved Inspection Authority
2. AMPP: Asset Maintenance Principles and Procedures
3. AM: Asset Management
4. APM: Asset Management Performance
5. BOM: Bill of Materials
6. BOQ: Bill of Quantities
7. CAPEX: Capital Expenditure
8. CBM: Condition Based Maintenance
9. CFO: Chief Financial Officer
10. CMMS: Computerised Maintenance Management System
11. CSIR: Council for Scientific and Industrial Research
12. DIFR: Disabling Injury Frequency Rates
13. EAM: Enterprise Asset Management
14. ER: Employee Relations
15. FAR: Fixed Asset Register
16. GFMAM: Global Forum on Maintenance and Asset Management
17. GM: General Manager
18. HR: Human Resources
19. IIMM: International Infrastructure Management Manual
20. ILP: Individual Learning Plan
21. IMO: International Monetary Organisation
22. IMS: Information Management Services
23. ISO: International Organisation for Standardisation
24. IRC: Infrastructure Report Card
25. ISPS: International Ship and Port Facility Security
26. KPI: Key Performance Indicator
27. LCC: Life Cycle Costing
28. LIS: Logistics Information System
29. MDS: Market Demand Strategy
30. MOU: Memorandum of Understanding
31. MRP: Manufacturing Resource Planning
32. OEM: Original Equipment Manufacturer

33. OPEX: Operational Expenditure
34. OHS Act: Occupational Health and Safety Act
35. PAS: Publicly Available Specification
36. PDCA: Plan Do Check Act
37. PPE: Personal Protective Equipment
38. PPM: Public Procurement Manual
39. RCM: Reliability Centered Maintenance
40. RME: Rail Maintenance Engineering
41. RUL: Remaining Useful Life
42. SAICE: South African Institute of Civil Engineering
43. SANS: South African National Standards
44. SAMSA: South African Maritime Safety Authority
45. SAMP: Strategic Asset Management Plan
46. SAP PM: Systems, Applications, and Products Plant Maintenance
47. SAP PMIS: Plant Maintenance Information System
48. SHERQ: Safety Health Environment Risk Quality
49. SOP: Standard Operating Procedure
50. TCP: Transnet Capital Projects
51. TFR: Transnet Freight Rail
52. TGC: Transnet Group Capital
53. TNPA: Transnet National Ports Authority
54. TPT: Transnet Port Terminals
55. TPL: Transnet Pipelines

1. INTRODUCTION

1.1 BACKGROUND

Ports act as the main link between a country's logistic supply chain and its trading partners. Ports provide infrastructure and facilities that enable cargo to be handled, stored, and moved inland using other modes of transportation such as trucks or trains. Most Ports usually have deep-water channels and berths for docking. There is usually also storage space on the land adjacent to the quay walls, i.e., back of berth space for the stacking and sorting of cargo. The depth or draft of the water at the entrance channels and inside the basin, and at the berths determines the type and capacity/size of vessels it can receive. South Africa relies on shipping as their main mode of transport for the import and export of goods. It also gives the ports a competitive edge in terms of the international vessels calling to the ports with the increasing size of container vessels built in modern days (African, 2010).

Cargo leaving ports goes to the hinterland through the infrastructures network depicted in Figure 1.1. "To function properly, the links between ports and the hinterland must operate smoothly to avoid bottlenecks, particularly in the ports (African, 2010, p. 33)."

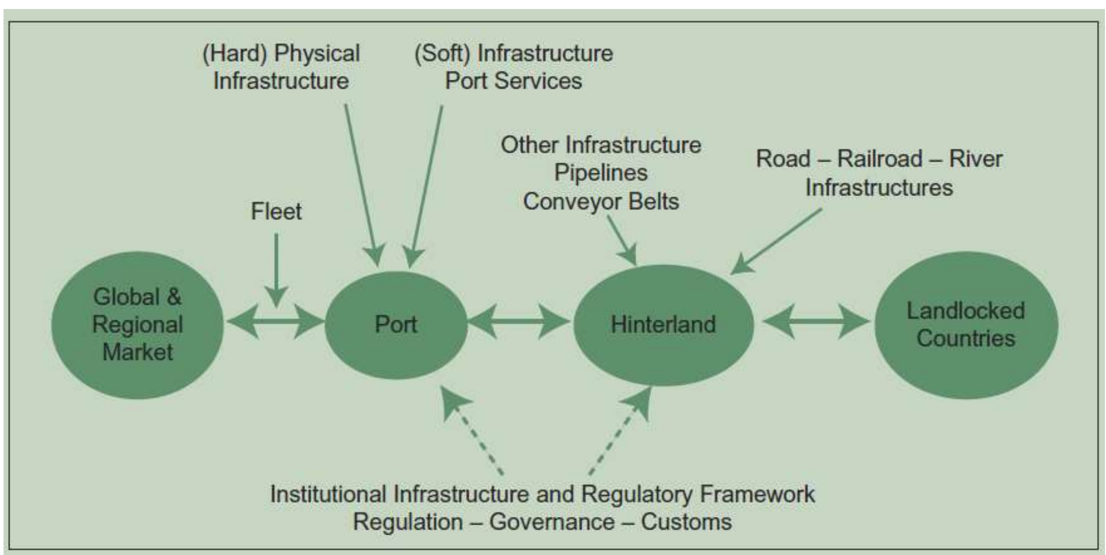


Fig. 1.1 The flow chain of cargo through ports and the hinterland.

(Source: 2010, African Development Report – Port Development in Africa)

1.1.1 WHY ASSET MANAGEMENT OF PORT INFRASTRUCTURE?

In recent years, the approach and focus on Infrastructure Asset Management and Maintenance by ports has greatly increased, with significant financial investments into the maintenance of infrastructure during the annual budgeting cycles ((CIDB), 2007). The investments are made in an effort to ensure that the assets of the ports, especially reinforced concrete structures in the marine environment, are well maintained and are safe for usage. The successful management of infrastructure requires implementing an effective asset management system coupled with a proactive maintenance program. There are key benefits that can be derived from an asset management framework for port infrastructure. The optimisation of the total cost of ownership in line with the organisation's strategic goals, achieving and exceeding the desired useful life of assets while providing exceptional levels of service to the asset users, and a reduction of any impacts to the environment are some of the key benefits (Grotheer, 2007)

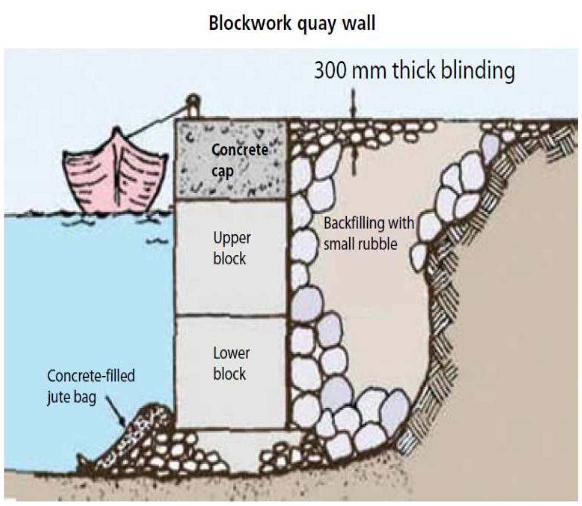
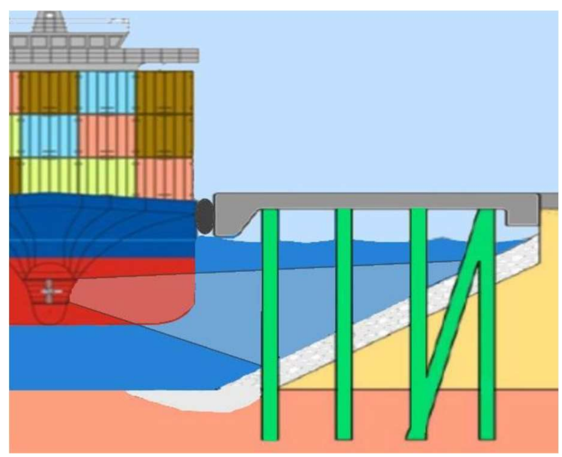
The TNPA is a regulated entity by the Ports Regulator of South Africa (PRSA). Therefore, any improvements or additions to port infrastructure are made in line with the port regulatory requirements. The PRSA's key function is to regulate the pricing and all other aspects of economic regulation according to the government's strategic objectives and per the National ports Act of 2005 (National Government of South Africa, 2018). TNPA has a Regulatory Asset Base (RAB) of about R70.00bn (TNPA, 2018). The RAB is a model that reflects the total asset value (debt plus equity) / capital employed in the business; the RAB reflects all assets belonging to the authority and includes fixed assets, Capital work in progress, and working capital (TNPA, 2018).

1.1.2 CONCRETE STRUCTURES IN PORTS

There are various types of concrete berthing structures inside ports, and their purpose is to provide a vertical face against which ships can safely berth. The front berth faces can either be solid berth structures or open berth structures, with the solid berths being the most commonly found structures in the South African Ports (Thoresen, 2014).

The difference between the two types of berthing structures are as follows:

Table 1.1. Differentiating between Solid & Open berthing structures
(Source: Thoresen, 2014)

Solid Structure Berth	**Open Structure Berth**
a) Berths that are made up of a solid vertical structure created to retain fill material against the opposite face of the structure (Thoresen, 2014). b) It is constructed either as gravity wall structures where the front wall uses its weight and friction to contain the fill or with a sheet pile structure, with an anchoring plate to retain the weight of the fill material (Thoresen, 2014).  Fig. 1.2 Solid Structure Berth Source: (Sciortino, 2010)	a) Open berths consist of structures supported by piles set slightly offshore from the natural extent of the land, extending away from the fill material (Thoresen, 2014). b) Open berths offer more flexibility in the method of construction but can present complicated dredging projects afterward and limits the amount of weight the berth can support and resist (Thoresen, 2014).  Fig. 1.3 Open berth quay wall Source: (Roelse, 2014)

Berthing structures are designed and constructed to safely resist the vertical loads caused by live loads, trucks, cranes, etc., and the horizontal loads from ship impacts, wind, and fill behind the structure (Thoresen, 2018).

Generally, solid berthing structures are considered more resistant to loading than open berthing structures, both vertically and horizontally. "Since the deadweight of a solid berth structure constitutes a greater part of the total structure weight than the deadweight of an open berth structure, the former is less sensitive to overloading (Thoresen, 2014)."

The main consideration in the design of marine structures is the foundation (Brown, 1994). For gravity quay walls, the determination of the shear strength, bearing capacity, and the compressive strength of fillmaterial is very necessary and important especially where the quay wall will be acting as an earth retaining structure. This would also apply to earth retaining sheet piled wall quays. In open piled structures, only shear strength and bearing capacity are required (Brown, 1994).

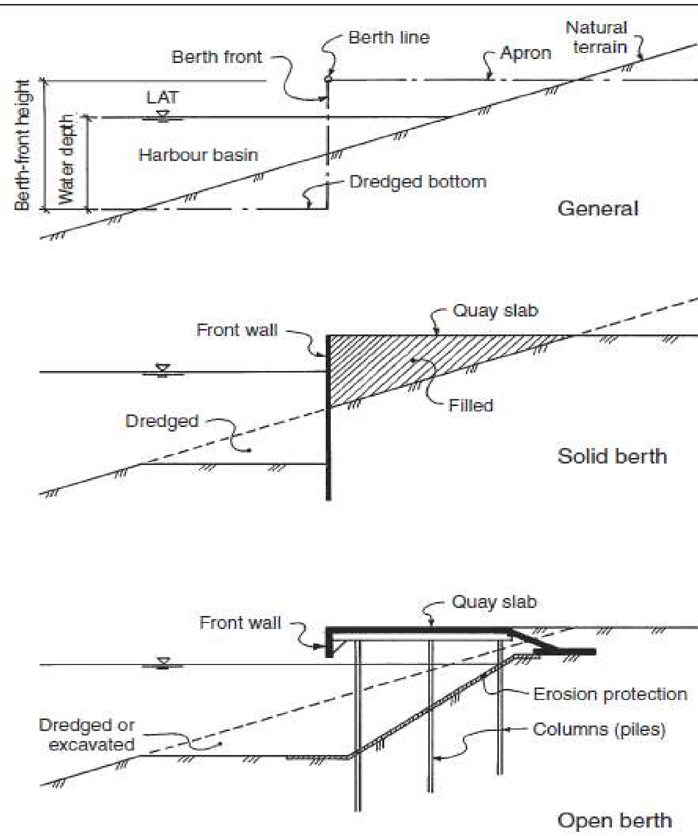


Fig.1.4. Indicating Solid & Open berthing structures
(Source: Thoresen, 2014)

The most common types of concrete mooring/berthing structures in South African Ports are:

- **Quays** – One or more berths continuously bordering on and in contact with a land or dock area. The quay apron reaches the quay front over the entire length of the berth. Quay structures fall into three categories: gravity section, sheet pile section, and open-piled structures. Designers need to know the merits and limitations of these structures (Brown, 1994).
- **Jetty / Pier** – A structure projecting into the water. The tendency is to use the term Jetty for open structures on piles only (Brown, 1994).
- **Dolphin berth** – Is a berth which does not have an apron over its full length but usually consists of a platform at mid-ships and a system of breasting and mooring dolphins interconnected with catwalks. The platform is usually connected to the land through an access bridge (Brown, 1994).

The Port Engineering handbook vol.1 (Brown, 1994) states that the design life of a structure is dependant mainly on the amount of time that the structure is intended to fulfil the function for which it is initially constructed, and not the length of time that a structure is capable of standing before major maintenance or reconstruction required. The minimum design lives recommended for typical marine structures by the Port Engineering Handbook are as seen below on:

Table 1.2. Minimum design lives recommended for typical port marine structures (Source: Port Engineering Handbook Vol.1, Pg. 2-38, 1994)

i.	Quay walls: Block & Caisson -	60 years
ii.	Quay walls: Pile & Beam -	35 years
iii.	Dolphin berths: -	35 years
iv.	Open Jetties -	35 years
v.	Superstructure works -	30 years

Stone and wood were materials predominantly used to construct Port structures before the advent of reinforced concrete. Stone and wood have been available as construction materials for many centuries. Some evidence of structures constructed from timber is still visible in some of the older South African ports. The disadvantage of using these materials is that only compressive forces can be sustained, although wood does have some limited tensile strength (Gijt, 2010).

With the development from cast iron to steel and later, around the 1900s, reinforced concrete, it became possible to sustain bending moments. This resulted in more slender construction and increased spans (Gijt, 2010). In the present day, reinforced concrete and steel are the most used construction materials in Port structures.

The various concrete berthing structures, as mentioned above, are, however, very susceptible to concrete deterioration due to the aggressive environment in which they exist. Reinforced concrete deterioration is a major factor that affects reinforced concrete structures in the marine environment and can reduce the long-term performance of concrete structures inside ports. The deterioration of concrete is not only dependant on the material composition and construction processes but is also largely dependent on the climatic conditions and environment that the concrete is exposed to during its lifecycle (MG. Stewart, 2010). Alkali Silica Reaction (ASR) and Chloride ingress are the major causes of reinforced concrete deterioration, and the durability of concrete, as well as the concrete cover to the concrete, are vitally important (Beushausen, 2015). The deterioration of reinforced concrete is apparent at the high watermark of marine structures. It manifests itself in cracking and spalling because of the corrosion of the reinforcing steel within the concrete structure rendering the structure unsafe to perform its intended function if left unattended. It is of vital importance that the condition of concrete structures are regularly monitored and assessed. Maintenance regularly following the regimes set out in the maintenance plans and determination of the Remaining Useful Life (RUL) of the structures is essential as part of the asset management framework used by the port (T Mneney, 2015).

1.2 PROBLEM STATEMENT

The existence and implementation of an effective Asset Management Framework in TNPA comparable with other leading ports for managing reinforced concrete assets for the berthing of vessels and handling of cargo is essential to ensuring guaranteed levels of service to customers. The return on investment for assets, improved efficiency, a proactive approach to Asset Management, and financial benefits for the organisation. The TNPA is required to ensure that the concrete infrastructure assets are in a safe and reliable state for the daily operations in order to generate revenue for the country.

1.2.1 RESEARCH QUESTIONS

Some question that needs to be asked by TNPA's concrete infrastructure asset owners or custodians are:

1) Does TNPA have an Asset Management system or Framework?
2) Is adequate asset maintenance being conducted at the correct cycles on the concrete assets?
3) How do TNPA's infrastructure asset management and maintenance systems compare to some of the major international ports?

Such questions can prove difficult to answer.

1.3 RESEARCH OBJECTIVE

This dissertation seeks to establish if an Asset Management Framework / System exists at TNPA and reviews how it aligns with other ports. The dissertation also examines the current asset maintenance systems and procedures for concrete structures within TNPA and their alignment to the industry best practices.

1.3.1 LIMITATIONS OF DISSERTATION

The dissertation primarily makes use of Transnet National Ports Authority information, standards, and procedures as well as online data sources for other international ports and asset management literature.

1.3.2 DISSERTATION ORGANISATION

The dissertation will follow the sequence below:

LAYOUT OF MINOR DISSERTATION

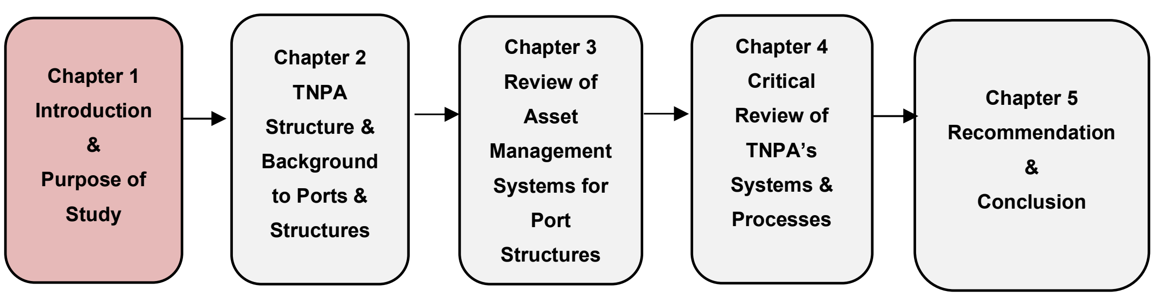


Fig.1.5 Dissertation Flow Chart

Chapter 1 – provides a background to the purpose of the study and seeks to give context for the study. An overview of the National Ports Authority footprint along the South African coastline is shown. A brief history of the ports emphasizing the first types of concrete structures is given, and Asset management for concrete structures is defined. The research objectives and the layout of the dissertation are also outlined in this chapter.

Chapter 2 – An overview of the South African Ports is given along the entire South African coastline. The prevailing ocean currents affecting the port structures are described, and climate change effects on port infrastructure.

Chapter 3 – This chapter defines Asset Management and the elements of an Infrastructure Management System; the chapter also does a comprehensive review of the Asset Management strategies of other international ports and presents an overview of TNPA's asset management and maintenance approach of their Infrastructure.

Chapter 4 – Gives a critical review of TNPA systems concerning their concrete infrastructure. It also seeks to point out any shortcomings in comparison to the international ports.

Chapter 5 – A conclusion is drawn from the findings and analysis of the information, and recommendations are made for TNPA to consider.

2. CHAPTER 2

2.1 INTRODUCTION

In South Africa, ports are owned and managed by Transnet National Ports Authority (TNPA). Transnet National Ports Authority (TNPA) is one of the divisions under Transnet SOC with a large asset base of Infrastructure, especially marine concrete structures for the docking of vessels and transfer of goods. The National Ports Act 2005 (Act No. 12 of 2005) regulates TNPA, and some of TNPA's core functions are the planning, provision, maintenance, and improvement of port infrastructure. Currently, there are eight commercial ports along the South African coastline with key concrete infrastructure for the berthing of vessels. The management and maintenance of concrete infrastructure are done through the Port Engineer's department.

Fig 2.1 Illustrates the eight commercial TNPA Ports along the South African coastline, with Richards Bay along the East coast down past Cape Town and up to Port Nolloth, the ninth port on the West coast. Port Nolloth is the only port that is not a commercial port in the TNPA port system, with plans for rehabilitation and expansion in the future.

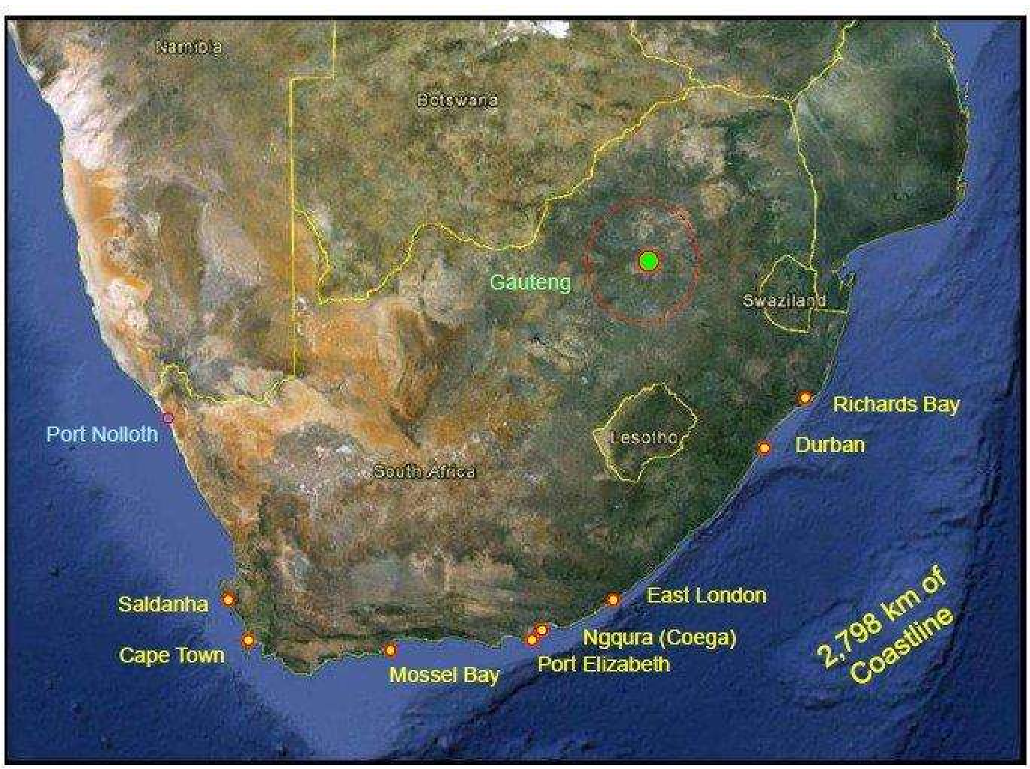


Fig: 2.1. Overview of TNPA Ports along the SA Coastline

(Source: National Port Plans (NPP) 2017, TNPA)

TNPA's ports are grouped into three main regions, namely: The Eastern Region, the Central Region, and the Western Region (TNPA Infrastructure, 2017). The breakdown is given in Table 2.1

Table 2.1 Grouping of TNPA ports according to regions
(Source: National Port Plans (NPP) 2017, TNPA)

EASTERN REGION	**CENTRAL REGION**	**WESTERN REGION**
1. Port of Richards Bay 2. Port of Durban 3.*Proposed Durban Dig Out Port*	1. Port of East London 2. Port of Ngqura 3. Port of Port Elizabeth	1. Port of Mossel Bay 2. Port of Cape Town 3. Port of Saldanha Bay 4*. Port of Port Nolloth* *5. Proposed Port of Boegoebaai*

2.2 PORT OF RICHARDS BAY

The South African government decided to build a deep-sea harbour at Richards Bay in 1965 in response to the potential of coal export from Kwa-Zulu Natal and the nearby provinces. Construction work began in 1972, and four years later, on 1 April 1976, the new harbour opened. The one-time lagoon was transformed into a 19m deep port (Ports & Ships S. , 2017). The port has one of the largest bulk coal terminals globally and focuses mainly on coal export and other dry bulk handling. The port occupies about 2157 hectares of land area and has about 23 operational berths with public and private operators (Strategies(TIPS), 2014). The concrete structures in the port include gravity quay walls, which are solid or vertical structures in the form of blockwork with a reinforced concrete capping type, a common type across the ports. There are also caisson quay walls, counterfort quay walls, and sheet piled walls with anchored tiebacks; the latter is a closed structure but not a gravity type structure as the anchoring plate contains the weight of the fill material. The port also has open structures in the form of jetties, which consist of a reinforced concrete deck on piles (Smith, 2016).

2.3 PORT OF DURBAN

The port is located on the East Coast of South Africa; the port’s first two breakwaters were built in the 1850s, designed to force the flow of water down the channel and to scour the entrance (Russell, 1982). The development of the port dates as far back as the year 1855 intended for servicing the Witwatersrand industrial region (McKenna, 2009). The port has a total land and water area of about 1854 hectares and has 59 active berths. The most common berthing structures are solid quays with blockwork as well as caisson diagram walls. There is also some sheet piled walls with anchored tiebacks and open structures such as a deck on pile type jetties. The Port's main commodity focus is containers, and the port accounts for 64% of the country’s containers handled. It also focuses on liquid bulk handling and automotive, grains, forestry agriculture products, coal, steel, and passengers. At present, it is the busiest port in Africa with the best-equipped container terminal in the region. It also boasts the largest and busiest container and petroleum terminals in the country; there are plans for further expansion with the proposed Durban Dig Out Port (Strategies(TIPS), 2014).

2.4 PORT OF PORT ELIZABETH

The port first received port/harbour status in the year 1825 and rapidly grew to become a principal port for export trade (Strategies(TIPS), 2014). The first breakwater structures were constructed in 1856 and 1866, including some timber structures later replaced by cast iron (Ports & Ships, 2017). Large-scale expansion of the port infrastructure took place in the 1930s, with the construction of the Charl Malan Quay blockwork and concrete capping gravity structure (between 1930 and 1935), and No. 2 Quay (between 1932 and 1936) also blockwork and concrete capping gravity structure. The Tanker Berth which is a deck on pile open structure was constructed (between 1936 and 1938), as well as the conversion of South Jetty into a slipway during 1940 – 1943, which is a deck on pile type structure (Straton, 2015).

In 1899, works began on the 256m by 18m Dom Pedro, and by 1902 a wooden open structure was later converted to a reinforced concrete deck on pile structure (Straton, 2015). As one of the oldest ports, the port structures, which can still be seen, ranging from timber to steel and concrete, with the bulk of structure being solid gravity, blockwork quay wall structures, and open deck on pile jetties and sheet piled walls. The typical cargos handled in Port of Port Elizabeth are containers, manganese ore, liquid bulk, automotive and general cargo, including agricultural products (TNPA Infrastructure, 2017).

2.5 PORT OF NGQURA

The most recent commercial port in the South African port system officially opened for operations in the year 2009. The main breakwater is the longest in South Africa (Ports & Ships S. , 2015). The port consists of seven berths totalling 2 100m of quay wall - four for containers, two for dry bulk and break-bulk cargo, and one for liquid bulk cargo. The berths were constructed as mass gravity, voided, concrete quay wall structures (Authority, 2010).

The concrete durability was of great importance, and all mass and reinforced concrete contained 25 to 30% fly ash as a cement extender to enhance the durability of the concrete mixes. Cement blended with slagment was also used to some degree due to its durability properties. The specified design strength of 40MPa concrete was for all reinforced concrete and 25MPa for mass concrete. A minimum cover of 100mm to the reinforcement for the front face of the quay wall, with a minimum of 60 mm in other areas (Plessis G. d., 2010). Ngqura is a deep-water port marketed as a container transhipment hub, the only South African port capable of handling the new generation container vessels. The short-term plans are for messy commodities such as manganese exports and liquid bulk imports that are moved to the Port of Ngqura. Simultaneously, the Ports of Port Elizabeth will continue to handle significant volumes of containers and vehicles (TNPA Infrastructure, 2017).

2.6 PORT OF EAST LONDON

Situated at the mouth of the Buffalo River, Port of East London is the only river port in South Africa. The development of East London's port structures dates back to around 1848 when the first stone jetty structure was built. Construction on the main harbour began in 1872, and in 1873, work began on the breakwater (South African History, 2011). East London was previously the main maize exporting terminal; however, due to a decline in recent years, automotive is the more dominant sector. The port has 12 commercial berths with about 2 410m of quay walls

(Strategies(TIPS), 2014). The most common type of quay structures is blockwork mass gravity and concrete quay wall structures. There is also some concrete sheet piled quay wall structures, which are also a solid type of quay structure, and jetty structures, which are open deck on pile type structures. The port has a dry-docking facility, which can handle ships of up to 200m with a maximum beam of 24.8m (Ports & Ships, 2011).

2.7 PORT OF CAPE TOWN

One of South Africa's oldest ports and is located on the world's busiest trade route (Strategies(TIPS), 2014). It is South Africa's second busiest container port and handles the most fruit exports in the country. The first harbour construction was a jetty built in 1654 by van Riebeeck. In 1860, the first breakwater was constructed, and a few years later, Victoria Basin was constructed, resulting in ten additional berths for ships (Ingpen B. , 2015). The port also has ship repair facilities and is situated adjacent to the waterfront leisure facilities (Strategies(TIPS), 2014). The port has 34 berths, with the majority being block work mass concrete closed quay structures, precast counterfort quay walls, caisson, deck, and mass concrete as well as some concrete sheet pile quay walls. There are also some piled jetty structures (Smith, 2016). The port of Cape Town continues its existing role as the primary container and general cargo for the Western Cape region (TNPA Infrastructure, 2017).

2.8 PORT OF SALDANHA BAY

The largest natural port in South Africa was completed in 1976 to support iron ore exports (W vd Molen, 2009). The port can accommodate vessels up to 21.5 metres deep. The port occupies 18300 hectares of land and water (Strategies(TIPS), 2014). Saldanha Bay is a common user Port of South Africa and has become one of the world's largest iron ore ports (Strategies(TIPS), 2014). The most common types of berthing structures are caisson quay walls, i.e., the 1km long caisson piers with precast, pre-stressed beams spanning in between to form the deck, precast counterfort units, as well as blockwork and mass concrete type quay walls (Smith, 2016). The infrastructure also consists of an 874m long multipurpose quay for the handling of breakbulk cargo and a 365m tanker berth at the end of the ore jetty with a permitted draught of 21.25m alongside (TNPA Ports & Ships, 2017). The port is earmarked to have facilities for ship and oilrig repair and to cater for the various aspects of the developing oil and gas industry (TNPA Ports & Ships, 2017).

2.9 PORT OF MOSSEL BAY

The country's smallest commercial port with limited infrastructure is about 87 years old. The earliest marine berthing structure was a timber jetty, which was constructed around the 1850s (Plessis D. B., 1976). The increase in harbour activity saw a concrete piled jetty 105 m long and 18 m wide equipped with two 4-t steam cranes planned to replace the timber structure (Plessis D. B., 1976). In 1973, the fishing industry was given the use of most of the existing harbour. In return, the Department of Trade & Industry provided the finance for a new 274-m long quay for the normal commercial activities of the port as well as a 180-m extension to the breakwater, thus creating a completely enclosed harbour (Plessis D. B., 1976). On the seaside, a 76m wide quay wall enclosed by an anchored concrete sheet pile wall protected against scouring action by a rubble toe (Plessis D. B., 1976). Wooden lead-in jetties, Concrete piled jetties, which are open structures, as well as a concrete sheet piled wall, which is a closed structure, are typical berthing structures in the port. The port of Mossel Bay is the only port in the country that operates two offshore mooring points within port limits, one as a marine tanker terminal and the other for feeder vessels between Durban and Cape Town (Strategies(TIPS), 2014).

2.10 PREVAILING OCEAN CURRENTS AND CLIMATE CHANGE IMPACT ON PORT CONCRETE STRUCTURES IN SOUTH AFRICA

The South African coastline's climatic conditions are characterised by swells, high waves, strong winds, high chloride concentration in the air, and fluctuating temperatures to which concrete structures are exposed. South Africa's coastline is influenced by two large-scale ocean currents, one on either side of South Africa, i.e., the Agulhas Current along the East and South coasts and the Benguela Current along the West coast (Isaacs, 2015).

Ports along the South African Coastline are subjected to different weather patterns, from high winds on the West Coast affecting the Ports of Saldana, the Port of Cape Town, and the Port of Mosselbay towards and past the Ports of Port Elizabeth and the Port of Ngqura towards the Port of East London (Isaacs, 2015). The Western coastal zone consisting mainly of the Benguela upwelling system exhibits intense upwelling due to a predicted increase in wind stress over the Southern Atlantic due to global climate change (Isaacs, 2015). Cold fronts, high winds, swells, occasional high waves, and rainfall characterise the aforementioned Ports. Concrete structures along the coast and in the ports have to withstand rough sea conditions brought upon by the Westerly winds causing abrasion to the structures from the constant knocking of structures and the development of cracks on the surface of the structures, which act as transport paths for deleterious substances (Isaacs, 2015).

Further, up the East Coast past the Port of East London, Port of Durban, until the Port of Richards Bay and towards Mozambique, the Agulhas Current is present, which is characterised by warmer waters (Isaacs, 2015). The Agulhas Current is accompanied by warm waters from the subtropics down the East coast of South Africa, passing the region of East London, due to the widening of the continental shelf, further offshore and the coastal waters become cooler (Isaacs, 2015). The infrastructure exposed to the Agulhas current also experiences higher temperatures and substantial rainfall, which creates ideal conditions for structures to crack and create passages for the transportation of chlorides as the structures saturate and then rapidly dry due to the higher temperatures in those regions (Isaacs, 2015).

South Africa's coastal ocean is open to the high wave fields of the Southern Ocean, and as a result, the port concrete structures are affected. Transnet National Ports Authority requires detailed information on the wave fields so that they can take necessary action during extreme wave predictions. TNPA makes use of the Council for Scientific and Industrial Research (CSIR) for the installation and maintenance of wave recorders, collecting the real-time wave measurements around the coast of South Africa (Marius Rossouw, 2011) (Isaacs, 2015).

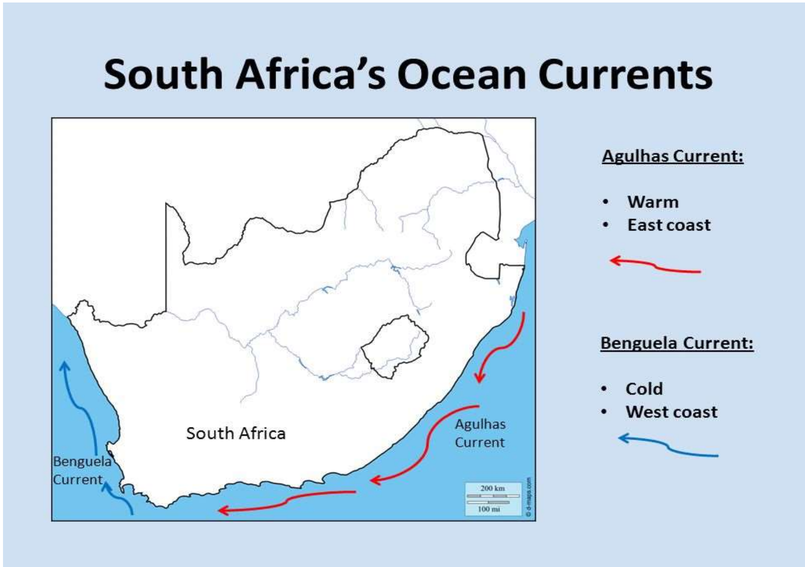


Fig.2.2 South Africa's Ocean Currents: Agulhas Current: Warm East coast, Benguela Current: Cold West Coast - (Source: Osborne, 2017)

2.11 PORTS AND CLIMATE CHANGE

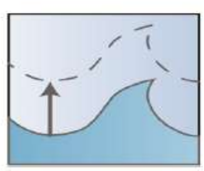
Climate change, loosely described, is a significant change in the measures of climate, such as temperature, rainfall, or wind, lasting for an extended period (Environmental Protection Agency, 2019). The change in climate patterns has been an ongoing phenomenon for decades, with events such as ice ages to extended periods of warmth throughout the planet's history (Environmental Protection Agency, 2019).

At the present time, human activities are greatly contributing to climate change through the emissions of greenhouse gases resulting in increased air and ocean temperatures, drought, melting ice and snow, rising sea levels, increased rainfall, flooding, and other influences (Environmental Protection Agency, 2019).

According to a study conducted by Phelp & Theron et al. (2013) of the CSIR, climate change is already affecting the South African coast and maritime operations. The study also recommends that in order to mitigate these impacts of climate change, more research directed at improving data/understanding of what is happening and what is likely to happen in the future and adaptation options available to the South African society is required (D Phelp, 2013).

The study also recommends changes in the design of ports structures in the long term, and improved forecasting and installing early warning systems are important for the reduction of the impacts of climate change (D Phelp, 2013).

Table 2.2 Climate Change Risks and potential impacts on seaport assets and operations Source: (Fisk, 2017)

Symbol	Parameter	Potential effects
	An increase in the severity of cyclones, storms and extreme weather events	• increased erosion, storm surge and flooding events • increased high wind events • increased lightning events
	Changes to rainfall patterns	• increased periods of drought and changes to the seasonality of rainfall • changes to water supply and availability • fog events (causing impacts to visibility and safety)
	Increasing temperatures	• increased incidents of very hot days and heatwaves • increased bushfire risk and intensity • increased average air and water temperature
	Sea-level rise	• more frequent erosion events • more frequent and far reaching tidal inundation associated with storm surge and storm tide events • permanent inundation of coastal areas • exacerbate the effect of cyclones and extreme storm events listed above

Cyclones and Storm events can increase erosion, cause storm surges, and flash floods. High waves can damage concrete quays, jetties, and other port structures, including container terminals and bulk storage facilities. Following these events, there is a rise in maintenance/repair costs, including emergency maintenance dredging. Other impacts from storms and cyclones are power outages and drainage issues. Cargo stored in the containers washes out to sea, including hazardous cargo that may affect the environment. (Fisk, 2017).

High wind events can result in damage to port infrastructure and equipment (Fisk, 2017). A change in rainfall patterns can lead to sand/sediment build up into the ports leading to an increase in dredging requirements. It could also impact vegetation and maintenance regimes (Fisk, 2017).

An increase in high temperatures can increase the rate at which deleterious substances penetrate concrete and result in an increase in rebar corrosion in concrete. The optimum relative humidity levels may also increase the rate of infiltration of deleterious substances (Bastidas-Arteaga, 2016). The deterioration process is accelerated, resulting in corrosion-induced cracking and spalling of reinforced concrete, which equates to costly and disruptive repairs and compromises concrete durability (MG Stewart, 2010).

Sea-level rise causes marine concrete structures to be exposed to increased wave action and corrosion from saltwater. The clearance between ships and crane booms may reduce, thereby affecting operations. Overhead clearances for vessels reduced, with a knock-on effect on rail and road transport (Fisk, 2017).

Table 2.3 Indicating sea-level change over the years – Source (D Phelp, 2013)

Station	Years of record	Sea-level change (mm per year ± 1 standard deviation)
Simons Town	1957-2007	+1.58±0.22
Mossel Bay	1958-2009	+0.33±0.35
Knysna	1960-2009	+1.81±0.54
Nelson Mandela Bay (Port Elizabeth)	1978-2009	+2.52±0.77
Buffalo City (East London)	1967-2009	+2.30±0.93
eThekwini (Durban)	1971-2009	+2.70±0.05

3. CHAPTER 3

3.0 INFRASTRUCTURE ASSET MANAGEMENT

Infrastructure asset management can be defined as an integrated and multifaceted set of processes focussed on assisting organisations in deciding to acquire, maintain and eventually dispose of assets after deriving maximum benefit, in the form of high levels of service, reduced maintenance costs, and safety risks during the useful lifecycle of the asset (Dietrich N. , 2015). It is essential to keep, maintain, and manage accurate data information as this will inform the planning and the execution of asset management and maintenance activities (Dietrich N. , 2015).

3.1 ASSET MANAGEMENT SYSTEMS

(Overview and Principles, Asset Lifecycle Activities and ISO Standards)

The practice of Asset management enables value realisation from assets in delivering the organisational objectives. There are standard measures used to get asset value and are dependent on the priorities of an organisation as well as its stakeholder expectations. (Tsang, ISO/CD 55000.2 Asset management — Overview, principles and terminology, 2012).

It is crucial to have a good understanding of what makes up the asset value, as well as the approaches used to determine it. Asset management, which is value-driven, represents the most efficient combination of costs, risks, performance, and anything that may affect the business goals of an organization, such as sustainability or damage to reputation over the life of its assets (Tsang, ISO/CD 55000.2 Asset management — Overview, principles and terminology, 2012). These aspects are all interconnected and, as such, any change to one aspect (such as reducing costs) will have an impact on all the others (Tsang, ISO/CD 55000.2 Asset management — Overview, principles and terminology, 2012).

Fig 3.1. Key Elements of Asset Management – Source ((NAMS) N. A., 2011)

Fig.3.2 BG&E's Asset Management Activities Cycle - Source: (BG&E, 2018)

Figures 3.1 & 3.2 illustrate the key elements of asset management and the cycle of activities to ensure (Australasia, 2017):

- Levels of service offered by the asset/organisation are specified,
- Future demand – the effect on future service delivery and the attainment thereof.
- Life cycle management plan indicating the management of existing and future assets for the provision of the specified levels of service throughout the lifecycle of the asset,

- Financial summary of the funds required to provide the services,
- Asset management practices,
- Monitoring of the plan to ensure attainment of the required objectives,
- Asset management improvement plan (Australasia, 2017, p. 11).

3.1.1 ISO ASSET MANAGEMENT STANDARDS

The three ISO Asset Management (AM) Standards that are applicable to all organizations that are responsible for asset management are:

- ISO 55000 Asset management – Overview, principles, and terminology
- ISO 55001 Asset management – Management systems - Requirements
- ISO 55002 Asset management – Management systems - Guidelines for the application of ISO 55001 ((NAMS) N. Z., 2014, p. 4).

Although ISO AM standards are concentrated on the managing of physical assets, they can be applied to any asset type regardless of the organization size ((NAMS) N. Z., 2014).

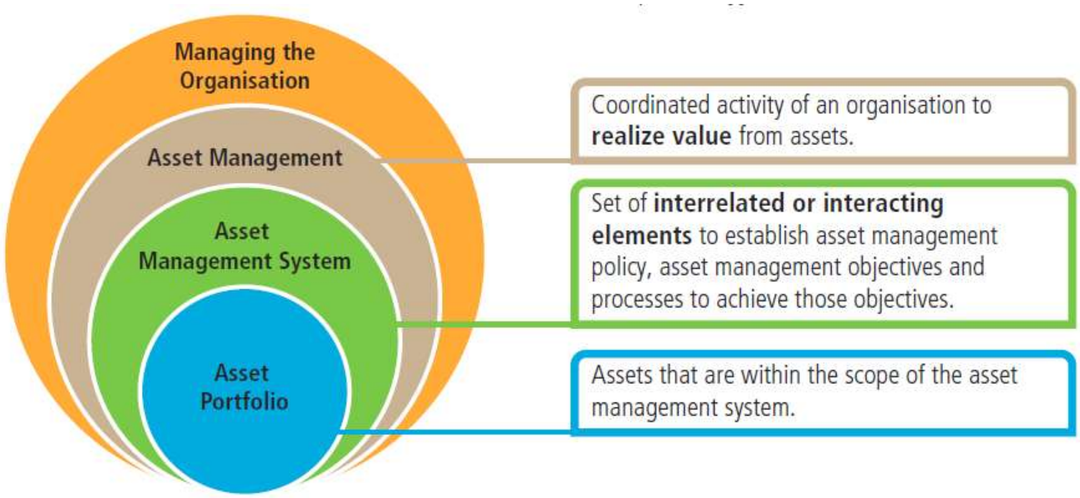


Fig.3.3. Asset Management and the Asset Management System

Source: (Heisler, 2014)

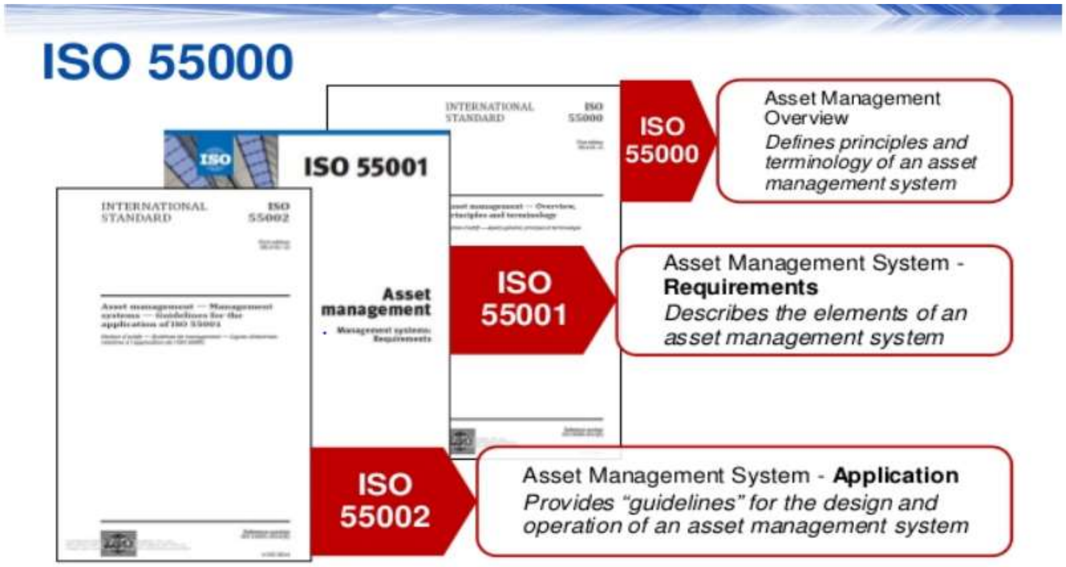


Fig.3.4 Asset Management and the Asset Management System

Source: (Amarra, 2015)

3.1.2 ISO 55001 – ASSET MANAGEMENT SYSTEM REQUIREMENTS

An asset management system comprises a set of interrelated or interacting elements to establish an asset management policy and objectives as well as the processes to achieve the objectives (Heisler, 2014).

ISO 55001 specifies requirements to establish, implement, improve, and maintain an asset management system (ISO/PC 251, 2014). It is applicable to any type of organisation (ISO/PC 251, 2014). An integrated asset management system is essential for managers of physical assets to either create or deliver services or products. The creation and adoption of an asset management system give assurance of the achievement of company objectives consistently and sustainably (ISO/PC 251, 2014). The primary users intended to benefit from the ISO 55001 International Standard are:

- Those involved in the formulation, implementation, maintenance, and enhancement of an asset management system;
- People who deliver asset management activities and service providers;
- The parties used to assess an organisation's ability to meet its legal, regulatory, and contractual requirements, including its own requirements, the parties could be internal or external to the organisation (ISO/PC 251, 2014).

The ISO 55001 standard enables alignment and integration of an asset management system with requirements (ISO/PC 251, 2014).

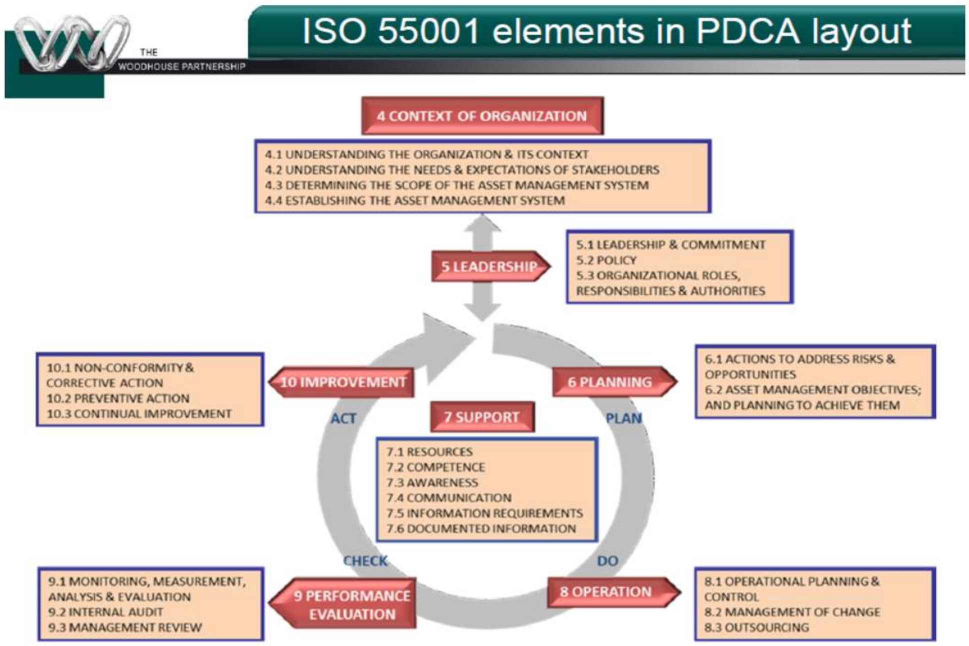


Fig. 3.5. Asset Management System Elements (ISO 55001 Elements in Plan Do Check & Act Layout). Source: (Veracity Asset Management Group, 2015)

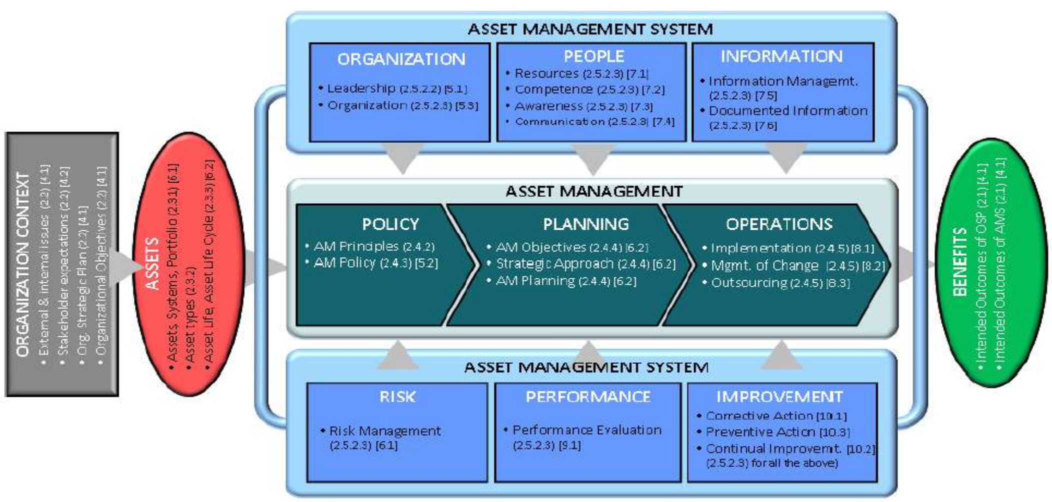


Fig. 3.6. Key Concepts Covered in ISO 55000 and Alignment with ISO 55001
Source: (Tsang, 2012)

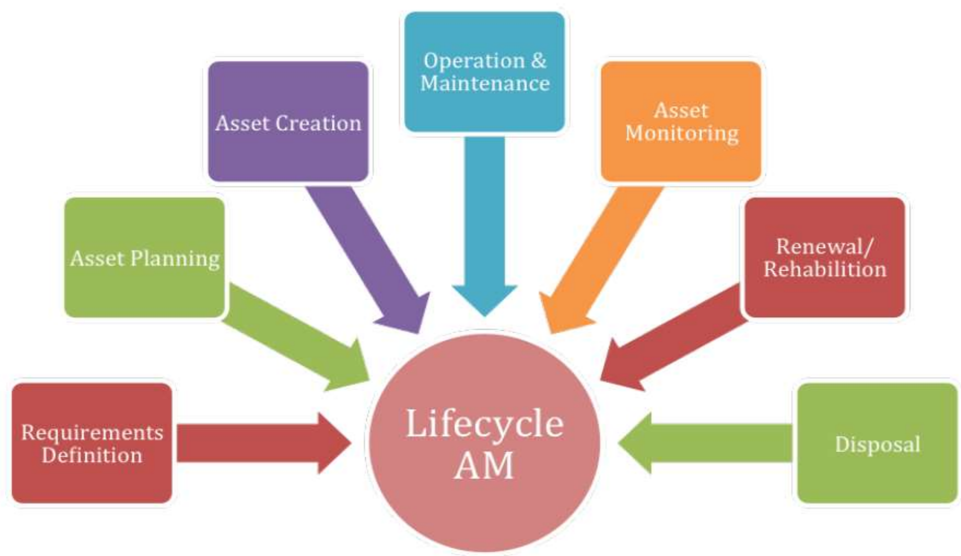


Fig 3.7. Asset Lifecycle Activities - Source: ((NAMS), 2011)

The main purpose of lifecycle asset management is to ensure that the lowest long-term costs are achieved, as opposed to short terms savings during decision-making (Duvenage, 2015).

There are various lifecycle activities, which aid in achieving this objective. Figure 3.7 illustrates the main activities comprised of the lifecycle approach to asset management comprises (Duvenage, 2015). Since this dissertation places a focus on existing concrete infrastructure, the activities of operation & maintenance, asset monitoring, and renewal/rehabilitation are of particular significance as they contribute to the functional operation of the port's concrete assets. An important part of the lifecycle asset management approach is to gain knowledge of the assets. It is important to subdivide an asset into components, as this will enable more detail for condition assessment and monitoring, depending on the asset type. The breaking down of an asset into components follows a hierarchy structure, which will assist in developing an asset register (Duvenage, 2015).

The International Infrastructure Management Manual (IIMM), currently in its fourth edition, has been developed and advanced over many years and is accepted broadly as a leading international document on infrastructure AM (NAMS, 2014). "The IIMM provides valuable guidance to organizations on how to implement good AM practice for infrastructure assets and includes over 100 case studies demonstrating good practice across a wide range of assets and countries" (NAMS, 2014, p. 5).

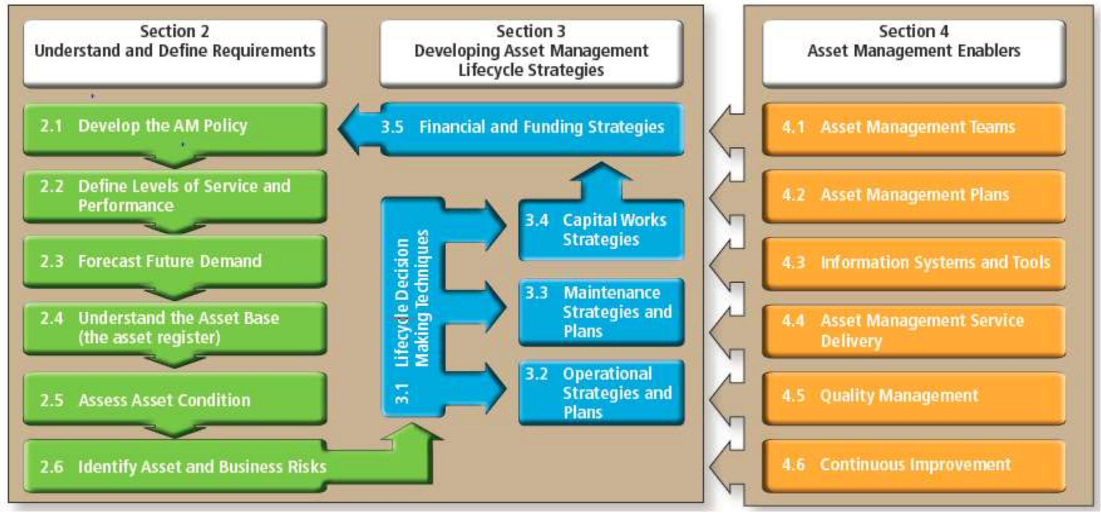


Fig. 3.8. The Asset Management Process (sourced from IIMM 2018, p1/9)

3.1.3 ASSET & MAINTENANCE MANAGEMENT

Asset management and maintenance management are terms commonly used interchangeably and synonymously by most people in the industry; however, even though the two practices have some commonalities and are very valuable tools, they are, in fact, both unique. Usually, most organisations already have one or more asset management systems in place with some elements of maintenance management (Paul E Haglar Jr, 2012).

Asset management is a strategically focused approach to make well-informed decisions relating to the development, use, maintenance, repair, rehabilitation, and preservation of an organization's infrastructure. It assists organizations in making critical decisions required to achieve a return on investment and the extended useful life of the assets (Paul E Haglar Jr, 2012).

Maintenance management is the process that plays a role in ensuring asset and equipment reliability by taking the required steps with the necessary skills and resources (Paul E Haglar Jr, 2012). Maintenance Management and Asset Management can take place at the same time and work conjointly, which is essential for the effective use of resources for the execution of repairs and maintenance on infrastructure assets of an organisation (Paul E Haglar Jr, 2012). The four primary fundamentals for maintenance management include Planning, Organizing, Scheduling, and Controlling. If the key elements of these fundamentals are satisfied, this could lead to an organization having very effective and reliable asset maintenance practices (Paul E Haglar Jr, 2012).

3.2 PORT INFRASTRUCTURE MANAGEMENT SYSTEM FOR CONCRETE STRUCTURES

PAS 55 and ISO 55000/55001 Asset Management Systems are being utilised and adapted by most international ports in order to properly govern the critical assets throughout the asset lifecycle (Allianz Global, 2016).

A port Asset Management System (AMS) can be used to monitor and maintain concrete and other assets owned by a port group, port, or department within a port (Allianz Global, 2016). It can be applied to tangible assets, such as concrete structures in the form of quay walls (gravity, sheet piled, caisson, and counterfort), jetties, and dolphins, as well as to intangible assets such as human capital, intellectual property, and financial assets (Allianz Global, 2016).

3.3 REVIEW OF EXISTING PORT ASSET MANAGEMENT SYSTEMS

3.3.1 ARC MARINE – MARINE PORT STRUCTURE GUIDANCE

Most Port Infrastructure management are members of The World Association for Waterborne Transport Infrastructure (PIANC). PIANC is an international organisation that addresses matters regarding the subject of navigable waterway traffic in ports and other waterways and advises on standards—known as the International Navigation Association PIANC (Allianz Global, 2016).

Most concrete infrastructure in ports of well-developed countries is over 100 years old and continues to perform beyond its expected life.

One of the important points highlighted in the paper as a general point around Health and Safety Executive's (HSE) regulations is that the time and thought invested during the initial stages of a project pays dividends not only in better Health and Safety but also in:

- Reduced owner's costs, maintenance, etc.
- Reduction in time spent finding relevant information

- Reliable costs & schedules
- Communication improvement
- Improvement in the end-product quality

In this context, an asset management system is defined as a system to monitor and maintain assets for ports, a group of ports, or a department within a port. The assets include both tangible, i.e., concrete structures, equipment, buildings, etc. and intangible assets, i.e., finance, people, intellectual property (Allianz Global, 2016).

The British Standards Institution (BSI) asset management system (AMS) that are adhered to by ARC Marine are PAS 55 and ISO 55000 & 55001. The Marine Port Structure guide for Arch Marine also highlights the importance of Asset Management Systems (AMS) and states that AMS's can be broken down into guidance notes, tools, and enablers for ports to:

a) Keep accurate information records for each and every asset
b) State of asset base assessment
c) Contingency plans review and amendment
d) Plan assets for the future
e) Linkage of assets to port plans
f) Assessment of condition & criticality of assets

AMS's which are specific to ports are usually intended for use by all departments within a port group to ensure that there is an equal implementation of asset management across all departments. The system should enable recording of all active processes to enable an objective view by other users and, in the process, emphasise any problem areas requiring additional attention (Allianz Global, 2016). Decisions by management needs for investment, criteria for acquisitions, maintenance, renewals, and disposal are centered on the AMS (Allianz Global, 2016).

The key areas covered by port-specific AMS's are:

a) Planning
b) Policy
c) Strategy
d) Process Mapping
e) Asset Creation and Acquisition

f) Project Management Process
g) Procurement of Plant and Equipment
h) Local Asset Management Objectives
i) Utilisation Specification
j) Local Maintenance and Inspection Plans
k) Renewal and Disposal
l) Business Planning Process (Allianz Global, 2016, p. 5)

As indicated above, the maintenance of assets forms an important part of the AMS. Table 3.1 indicates the five categories of maintenance, as described in the manual for road and bridge design BD63/07. Source: (Specialty, 2016)

Table 3.1 Five categories of inspection - Source: (Allianz Global, 2016)

Inspection Type	Description
Safety Inspection	Where a defect has been identified.
General Inspection	Visual inspection every 24 months.
Principal Inspection	Close visual inspection every 6 years.
Special Inspection	Inspection after a special event, e.g. extreme high tide event.
Inspection for assessment	Part of a structural assessment.

Visual inspections of quays annually or every two years from the quay and by boat, as well as through diver inspections, have become a widely accepted practice within the industry, and the same applies to the TNPA ports. A detailed report should be issued annually or every two years, cross-referencing previous survey work, including issues of repairs and maintenance, which still need to be addressed. The report should include budget estimates for materials, repairs, and supervision, also indicating the different types of structures, the type of inspection to be conducted and the frequency of the inspections, and how to address the issues identified, including electrical, hydraulic, and lifting equipment (Allianz Global, 2016).
Certain considerations must be taken into account when planning or developing a port, such as the alignment of the structure, the civil and structural design

requirements, vessel growth projections, weather conditions, and type of fendering systems to be utilized (Allianz Global, 2016). Most ports have clear guidance on how to address defects and maintenance issues. The Oil Companies International Marine Forum (OCIMF) publication “Jetty Maintenance & Inspection Guide” which provides effective maintenance of critical items of equipment at oil and gas terminals, gives advice on different items of equipment together with proactive & reactive maintenance guidance as an additional source of information to reference (Allianz Global, 2016).

Reinforced concrete is a material that is extensively used in port structures for docking vessels and ships. Concrete can be used below and above water, but care should be taken to ensure that the required procedures and standards are followed. Reinforced concrete structures are susceptible to two main forms of deterioration, and these are chloride ingress and Alkali Silica Reaction (ASR) (Allianz Global, 2016).

Chloride ingress into the concrete due to the existence of cracks within the concrete creates a pathway for chloride ions to penetrate the marine concrete structure. The reinforcing steel within the concrete is affected, causing rusting, which eventually results in cracking and spalling if left unattended. This is mainly in the structures that are in the splash zone and are not fully submerged. Cathodic protection is a common way of dealing with the deterioration of steel (Allianz Global, 2016).

ASR is a phenomenon where the cement or aggregate is contaminated with high levels of chloride, producing hygroscopic gel that absorbs moisture and swells. It manifests as surface deposits and is associated with wetting and drying cycles and can also lead to severe concrete deterioration by creating pathways for other chemicals to attack the concrete (Allianz Global, 2016). In the UK, the British Standards BS1200 governs the chloride levels for aggregates to ensure that the chloride levels are as low as possible. The types of cement are also grouped/ classed from high to medium to low alkali, with the high alkali cement posing a greater risk of ASR attack during the mixing process as compared to the low alkali cement with a low risk (Allianz Global, 2016).

3.3.2 MARINE ASSET MANAGEMENT PLAN – CITY OF POWELL RIVER

The City of Powell River is located on the northern Sunshine Coast of South-western British Columbia, Canada. The Asset Management Plan (AMP) covers the infrastructure assets that serve the City of Powell River's marine infrastructure needs. The infrastructure provides marine services to the public, commercial anglers, transient marine traffic, and recreational users (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

The concrete infrastructure consists of boat ramps for the launching of vessels and marina structures for the mooring of pleasure craft and commercial and transient vessels (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). The marina structures may be fixed, i.e., piled jetty, or floating, in the form of a pontoon type (M Buglar, 1994). Fixed moorings usually consist of piled walkways (jetties) and mooring piles, whilst pontoons are usually used for floating moorings (M Buglar, 1994).

The City of Powell River defines an asset management plan as a comprehensive process intended to ensure service delivery from marine infrastructure in a financially sustainable manner. The plan defines the services provided, as well as the funds required to provide the services. These plans are very useful in terms of long-term planning as well as committing funds for the future.

In this plan, it is stressed that future projections provided by the AMP should include the operations, maintenance, replacement of existing assets, and the construction of new assets must be budgeted/estimated over a certain planning period (in the case of the City of Powell it is 20 years and spread over each year) (RIVER, 2013).

Table 3.2 Key Stakeholders in the AM Plan – Source: (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013)

Key Stakeholder	Role in Asset Management Plan
Council	• To act as custodians for the community's assets. • To set levels of service, risk and cost standards. • To approve the Asset Management Plan and align the Strategic Plan and the Corporate Plan. • To approve the asset management program. • To ensure appropriate resources and funding are made available to support the asset management program.

Key Stakeholder	Role in Asset Management Plan
Chief Administrative Officer and Management Group	• To provide strategic advice and leadership in the management of infrastructure assets. • Ensure outcomes support the Corporate Strategic Plan. • To validate and challenge proposals to ensure they meet the Corporate Strategic Plan objectives and community service needs. • To ensure the community and key stakeholder inputs are integrated into asset management plans.
Managers and staff	• Establish current levels of service for assets, compare to benchmarks and community needs and identify gaps or challenges. • To draft asset management plans • To implement the asset management program with agreed resources. • To develop, implement and review the asset management program using the International Infrastructure Management Manual as a guide, documenting required allocation of funding and improvement plans for individual asset groups, using the principles of life-cycle costing. • To develop and implement maintenance, and capital works programs in accordance with the Asset Management Plan and Strategy, the Corporate Strategic Plan and the 5 Year Financial Plan. • Deliver Council approved 'levels of service' to agreed risk and cost standards. • To manage infrastructure assets in consideration of their long-term sustainability. • To develop and implement maintenance and capital works programs in accordance with asset management plans, and report to the Management Group and to Council.

3.3.2.1 Steps to be taken to Resolve City of Powell River's Funding Short Falls

The steps that the City of Powell can take in order to resolve funding shortfalls are as follows:

1. Improve the knowledge of the assets in order for accurate data recording in the asset inventory, asset performance, and instances when the required levels of services are not being met.
2. Improvement of operational efficiencies, maintenance, and asset life cycle cost optimization through the renewal and replacement of existing assets.
3. Risk identification and management for the provision of services by the infrastructure.

4. Negotiating between service levels and costs in order to guarantee end-user /customer satisfaction.
5. Identifying underutilised assets and disposing of them to realise savings in future operations and maintenance costs.
6. Stakeholder/customer engagement to ensure infrastructure provided meets their needs and is affordable.
7. Form Private Public Partnerships with external bodies where possible for service delivery (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

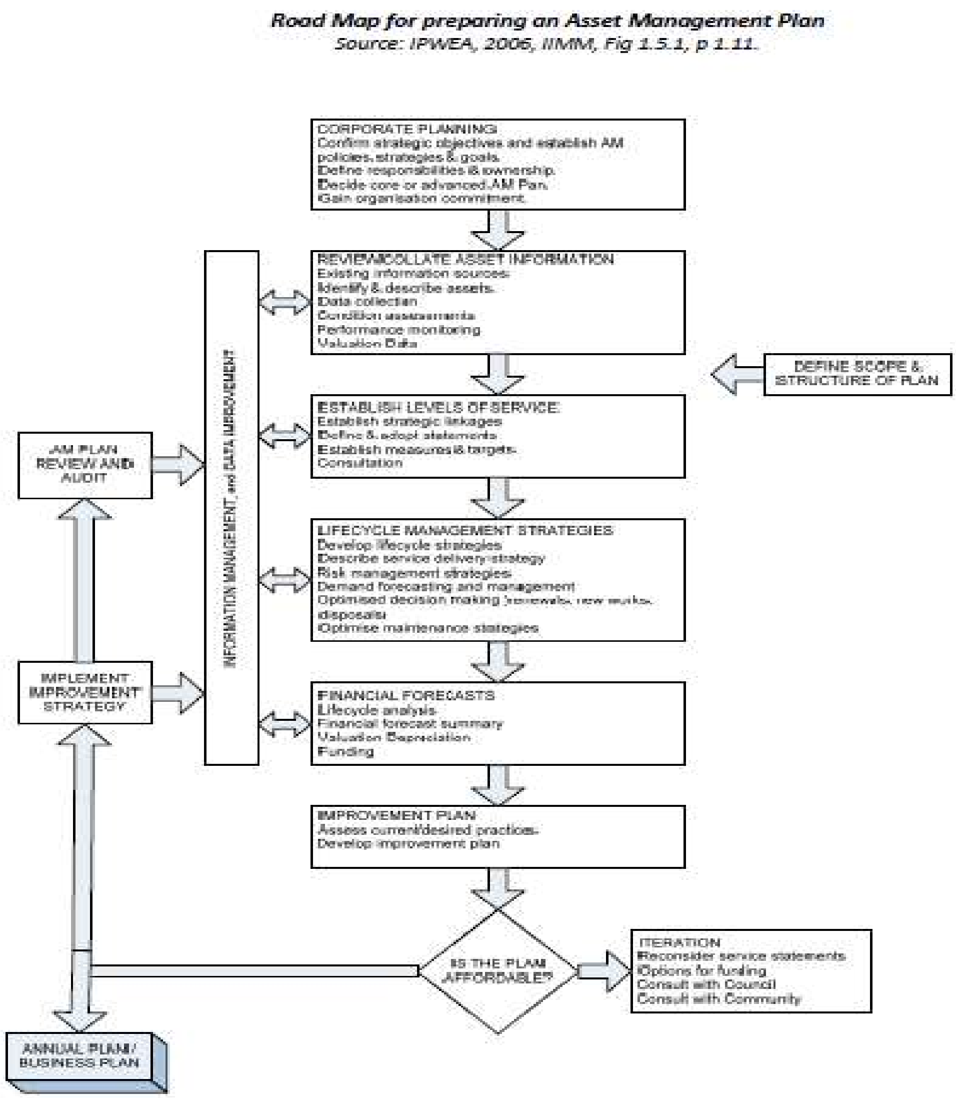


Fig 3.9 Road Map for preparation of Asset Management Plan

Source: (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013)

3.3.2.2 Main Goals and Objectives of the IAM Plan

The main goals and objectives of the plan for managing their concrete infrastructure assets are to meet high levels of service in a manner that is cost-effective to their organization and to ensure customer satisfaction. Some key elements of the IAM plan are as follows:

- Provision of a level of service as defined and to ensure performance by monitoring.
- Investment and provision of infrastructure ahead of demand through managing the demand.
- Ensuring that life cycle planning takes place and development of long-term management strategies that are cost-effective to ensure attainment of the defined service levels.
- Risk management.
- Long term financial planning

3.3.2.3 Level of Service

Level of Service is a method to define a service provided; in this context, it would relate to the infrastructure assets which service the users. It could be measured according to quality, quantity, risk, accessibility, and availability (Council, 2012). It is an important measure/indicator in terms of whether the objectives of the organization are met in terms of the service (assets) provided (Council, 2012).

The City of Powell defines service levels in two terms, namely:

1. **Community Levels of Service** - a community response to services provided.
2. **Technical Levels of Service** - are operational or technical measures of performance. These technical measures relate to the allocation of resources to service activities that the organization undertakes to best achieve the desired community outcomes and demonstrate effective organizational performance (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

The City's technical service measures are linked to their annual budgets, which cover marine operations, maintenance (i.e., inspections, condition assessments, float repair, pile assessment, etc.), renewals, and upgrades (City of Powell River, 2013).

Table 3.3. The Asset Management Improvement Plan generated from Powell River asset management plan – Source: (RIVER, 2013)

Task No	Task	Responsibility	Resources Required	Timeline
1	Separation of maintenance & operations budgets	Finance Department	Financial, Engineering & Operational services	6 months
2	Identification of critical assets for condition assessment	Engineering & Operational services department	Engineering, Operational services & Finance	12 months
3	Long term financial planning for asset renewals & upgrades	Financial Services Department	Financial Services staff	12 months
4	Undertake marine asset infrastructure condition monitoring to increase confidence limits.	Engineering & Operational services department	Various staff	24 months
5	Further integration of asset GIS database with an asset management plan	Engineering & Operational services department	Engineering, Operational services & Finance	24 months
6	Undertake community consultation	To be determined	To be determined	24 months
7	Performance measurements	Engineering & Operational services department	Engineering & Operational services department staff	continual

Demands Forecasting & Demand Management Plan - current situation and forecasts for demand drivers that may affect future service delivery and the utilisation of the assets (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). Developing and managing a demand management plan that will manage the existing assets, upgrading of existing assets, and the provision of new assets to meet future demand is key for City of Powel River (City of Powell River, 2013).

Life-Cycle Management Plan - details how the organisation plans to manage and operate the assets at the agreed levels of service while optimising the life cycle costs. The physical limitations of the asset, the asset capacity, and performance in accordance with the design criteria used, the asset condition from regular maintenance conducted on the structure, asset valuations as recorded in the asset inventory consisting of Current Replacement Cost, depreciable amount, average useful life. Lastly, the historical data detailing the historical costs, netbook value as well as annual amortization expenses of the marine assets (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

Infrastructure Risk Management Plan – This is an assessment of the risks associated with service derived from infrastructure assets. The risks are ranked from critical risks that will result in the loss or reduction in service from infrastructure assets (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). The risk assessment identifies credible risks, the likelihood of the risk event occurring, and the consequences should the event occur (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). “A risk rating is developed, which evaluates the risk and develops a risk treatment plan for non-acceptable risks (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).” The critical risks rated very high, require immediate corrective action, and require prioritised corrective action, together with the estimated residual risk (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

Routine Operations and Maintenance Plan - Routine maintenance is regular on-going work that is required to keep assets operational; this includes cases where parts of the asset fail, requiring immediate repair (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). Operations can influence marine assets if no regular maintenance is conducted on the assets. Maintenance is essential for ensuring and sustaining the useful condition of an asset (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). Maintenance is grouped into reactive, planned, and specific maintenance, with reactive being unplanned repair work in response to a service request. Planned maintenance is work that is identified and managed through a maintenance management system (MMS), which will include inspections as well as condition assessment of the asset and, in turn, forms a record of historical data (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). "Specific maintenance is the replacement of higher value components/sub-components of assets and is undertaken on a regular cycle (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013)."

An asset hierarchy should be developed, grouping the different marine infrastructure assets according to their criticality. Critical assets are assets that have a high consequence of failure. By identifying critical assets as well as the failure modes, the organization can be in a better position to plan better for maintenance and CAPEX budgets. The application of the relevant standards and specifications when conducting maintenance activities is essential in ensuring compliance of the work (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

Renewal and replacement plans contain expenditure done to restore, rehabilitate, replace or renew an existing asset to an adequate level of service potential (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). Work conducted to exceed an asset's original capability is regarded as an upgrade or new work expenditure (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). An asset inventory register is a critical tool to project the renewal costs by utilizing the year of acquisition and the remaining useful life to determine the renewal year (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). New works to create new assets that did not previously exist or works to upgrade or improve existing asset beyond their design capacity result from growth, social or environmental needs (City of Powell River, City of

Powell River - Marine Asset Management Plan, 2013). New project needs are assessed and ranked according to the benefits associated, risks associated with not providing assets, estimated delivery timeframes, and available budgets. The capital projects are included in the organisation's long-term, i.e., ten-year CAPEX plans (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

Financial Forecasts – the four key indicators for service delivery sustainability are Asset Renewal Funding Ratio, Long-term Life Cycle Costs, medium-term 10-year financial plans, and 10-year medium-term financial planning. Asset Renewal Funding Ratio is an important indicator as it indicates the 10 to 20-year forecasting of funds for renewal and or replacement in the long term - Life Cycle Costs are average costs required to sustain the service levels over the asset life cycle, and include maintenance, operations, and asset depreciation costs. The Medium-Term – 5-year financial planning period, as well as the Medium Term – 10-year financial planning period inclusive of operations, maintenance, and capital renewal costs (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). The funding strategy is mapped out in the City's long-term financial plans. "Expenditure and valuations projections in the AM Plan are based on best available data and currency, and accuracy of data is critical to effective asset and financial management" (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

Disposal plans contain all activities associated with the disposal of decommissioned assets, including a sale, demolition, or relocation (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

There are risks associated with failure to conduct maintenance, capital projects, or operations, which can have dire consequences for the users of the assets. The risks need to be incorporated in the Risk Management Plan (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

The asset management plan should be monitored on a regular basis for any processes which may need improvement. The type of Asset Management system currently in use for the City of Powell River is GIS software produced by ESRI, called ARC GIS. The asset inventory register is compiled and maintained by the Finance Department with support from the Engineering Department (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). The asset inventory register is assessed and verified on an annual basis according to their policies (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). The infrastructure, accounting services, and engineering departments are responsible for ensuring the maintenance and accuracy of the asset management system and its associated data (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

The asset management plan is reviewed during the annual budget planning processes and is updated annually to ensure it represents the current service level, asset values, operations, maintenance, capital renewal and replacement, capital upgrade/new, and asset disposal expenditure (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013). The projected expenditure values are incorporated into the Council's long-term financial plan (City of Powell River, City of Powell River - Marine Asset Management Plan, 2013).

Implementation of the Asset Management Plan & Strategy

The City of Powell River's asset management implementation aspirations are well on track and are a work in progress, with some key milestones having been achieved towards fulfilling their goal of embracing asset management principles in the management of their infrastructure assets. Following the development of the Asset Management Plan, which lists what has to be done, an Asset Management Strategy was developed, which outlines exactly how the plan objectives will be carried out (City of Powell River, 2014). An Asset Management Steering Committee (AMSC) was appointed by the Council to assist with making any Asset Management recommendations for the implementation of the AM objectives for Powell River Council (Birtig, 2015).

The strategy will assist the City in achieving its requirements of the Corporate Plan objectives and provide services in a financially sustainable manner. A detailed life cycle budget was developed for funds to replace assets optimally when they have reached their useful lives. Fig 3.10 below indicates the annual life cycle budget for Powell River across all asset categories (City of Powell River, 2013)

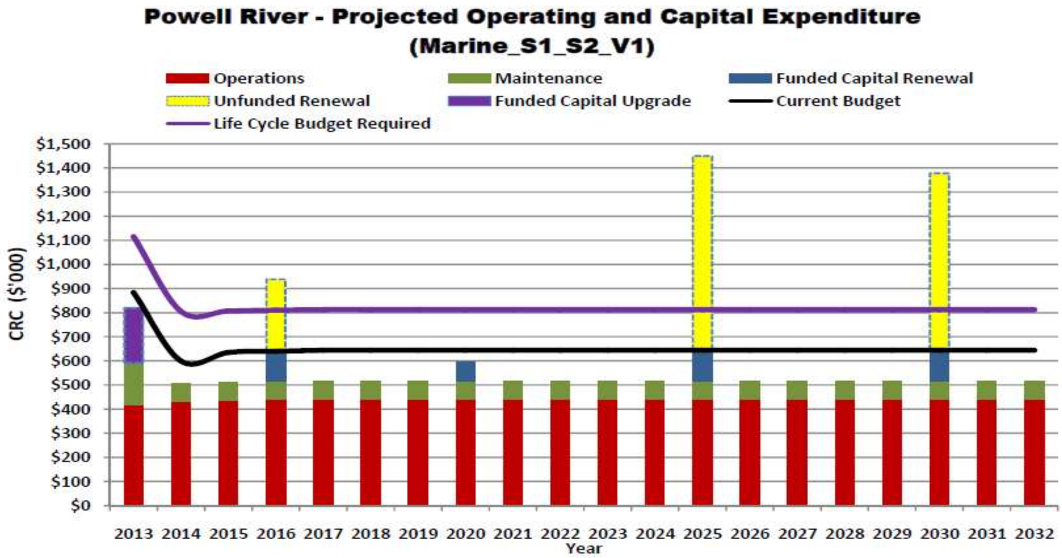
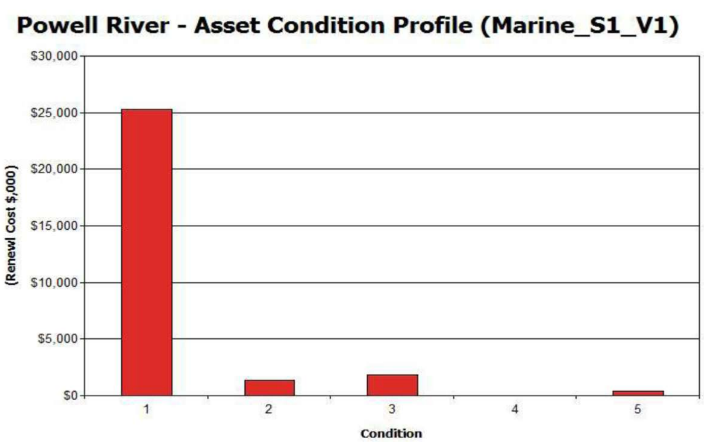


Fig 3.10 – Powell River – Projected Operating and Capital Expenditure Marine - Source: (City of Powell River, 2014)

Table 3.5 – Simple Grading Model – Source: (City of Powell River, 2013)



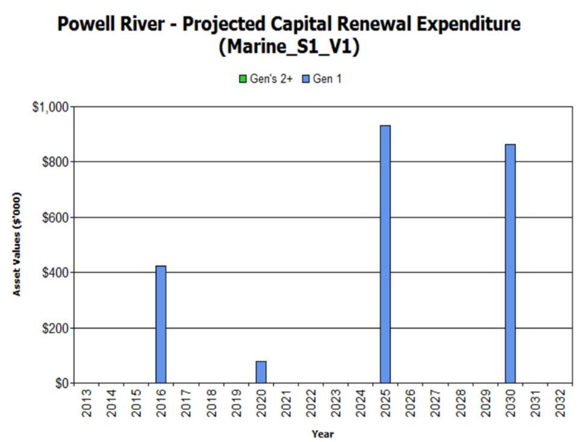


Figure 3.11 Asset Condition Profile Figure 3.12 Projected Capital Renewal expenditure

Condition Grading	Description of Condition
1	**Very Good:** only planned maintenance required
2	**Good:** minor maintenance required plus planned maintenance
3	**Fair:** significant maintenance required
4	**Poor:** significant renewal/rehabilitation required
5	**Very Poor:** physically unsound and/or beyond rehabilitation

As can be seen from figure 3.11 as well as table 3.5 above, the marine asset condition is still very good, with the bulk of the assets rated as very good.

It is imperative that the City of Powell River identify, understand, and manage any risks associated with operating, managing, and maintaining their marine infrastructure assets (Birtig, 2015). This will entail incorporating the risk management process in all the asset decision management processes like budgeting and the development of a risk management plan for the assets (Birtig, 2015).

The next step for the City of Powell River is to implement an Asset Management Information System (AMIS) by:

- Migrating data to the one repository
- Training staff to use AMIS software
- Training staff to use field devices to capture and retrieve data (Birtig, 2015)

The City of Powell River took a proactive approach to the managing of their assets even though there were no provincial or municipal requirements to do so.

3.3.3 STRATEGIC ASSET MANAGEMENT AT THE PORT OF MELBOURNE

The Port of Melbourne Corporation (PoMC), located in Victoria, Australia, embarked on a process of creating and implementing a strategic asset management programme with the aim of enabling the Port to understand, predict and influence the total life-cycle costs of its infrastructure assets reliably (Bianco, Giddings, 2010). The Port owns and manages a large asset base with an estimated total replacement value of AU$ 1.8 billion and has been working tirelessly to create and implement an asset Policy and Strategy. The key deliverables of the strategy are:

- Asset renewal forecast based on age, condition, level of service, and risk.
- Lifecycle planning for a better understanding of the total cost of ownership.
- Appreciating asset risk exposure and its influence on maintenance and renewal predictions.
- Optimised decisions around asset renewal and accurate determination of action plans for assets.

- Embedding Asset Management as a core business discipline (Bianco, Giddings, 2010).

The Ports legislated functions are to manage and develop the port in an economically, socially, and environmentally sustainable manner while providing cost-effective essential services and facilitating trade growth (Bianco, Giddings, 2010). It is also to integrate the Port with other infrastructure systems and management of the shipping channels (Bianco, Giddings, 2010).

PoMC is Australia's premier container port representing about 36% of Australia's container trade and is ranked in the top 50 ports globally. With about 3600 vessels calling at the port annually, PoMC relies greatly on its infrastructure assets. It is, therefore, essential that the infrastructure assets be continually managed over their life cycle to ensure the high levels of service offered to customers cost-effectively with minimal risk (Bianco, Giddings, 2010).

Of the vast amount of assets owned by the PoMC, their most valuable in terms of replacement costs and criticality to accommodate ships are their concrete Quays & Jetties, with a total of 34 containers, liquid bulk, breakbulk and automotive berths totaling about 7 kilometers of concrete quay length (Bianco, Giddings, 2010). From the number of assets owned by the Port, it is clear that they invest greatly in the maintenance, rehabilitation, and renewal of their assets (Bianco, Giddings, 2010).

3.3.3.1 The PoMC's Strategic Asset Management Policy

Adopted in 2008 (Bianco, Giddings, 2010), it places several obligations on the PoMC to implement and maintain the best asset management practices.

The fundamental activities to maintaining basic asset management are:

1) Maintaining a computerised Asset Management System that incorporates a detailed register of all infrastructure assets.
2) Ensuring proper interface between the Asset Management System and other corporate systems supporting asset management, e.g., Finance, document management system, and property.
3) Maintain an effective asset condition rating methodology framework for all assets and maintain a properly planned asset inspection regime to ensure timely reporting of defects and development of maintenance plans.
4) Keeping a valuation and costing history of assets with an applicable unit cost structure.

5) Ensure that infrastructure assets are maintained in a fit for purpose state and develop and manage a planned and unplanned maintenance register with their associated budgets.
6) Implement the necessary prescriptive based inspection and maintenance contracts with specialist service providers.
7) Ensure that assets comply with all the relevant Acts, Regulations, standards, and specifications governing the PoMC.
8) Develop and update standard operating policies and procedures for PoMC assets where required, and always have backup plans for critical assets (Bianco, Giddings, 2010).

The strategic asset management objectives for PoMC are; to employ demand management principles to minimize the need to create new or renew existing assets whilst understanding the risk exposure for all the assets. Assigning a responsibility, accountability, consult, and inform (RACI) matrix for the performance of assets (Bianco, Giddings, 2010).

Enforce the use of whole life cycle costing and discounted cash flow techniques for both existing and replacement assets and ensure that asset renewal decisions are based on return on investment (ROI) and whole life cycle capital, operations, and maintenance costs. Developing long-term renewal strategies based on risk exposure, level of service requirements, and commercial utilization (Bianco, Giddings, 2010).

The PoMC embarked on an improvement programme aimed at improving and achieving some key principles intended to consolidate and integrate the PoMC as a high performing world-class asset management organization (Bianco, Giddings, 2010).

The principles are to:

- Form a unified organisational focus with consistent policies, procedures, and clarity over responsibilities for asset performance (Bianco, Giddings, 2010).
- Embed asset management as a core business discipline within corporate processes, eliminate silo-based asset management processes, and improve corporate consistency.

- Transition from project-centric to whole-of-life philosophy and improve clarity over the measurement of asset performance and standardise the approach to life cycle planning and costing methodologies.
- Develop Asset Management Plans for key infrastructure assets that align and support service outcomes and corporate goals.
- Make sustainable decisions based on whole-of-life cycle costs, risk, level of service considerations, and return on investment.
- Develop and implement a suite of technology systems and tools to support the strategic asset management decision-making processes.
- Implement an appropriate best practice asset management-training programme for staff involved in asset management decision-making and build competency and intelligence in strategic asset management across the PoMC.
- Develop tools to assist with long term renewals planning and optimised renewals decision making (Bianco, Giddings, 2010, pp. 4-5).

The PoMC created a maturity model pyramid to illustrate how the improvement process was measured and benchmarked.

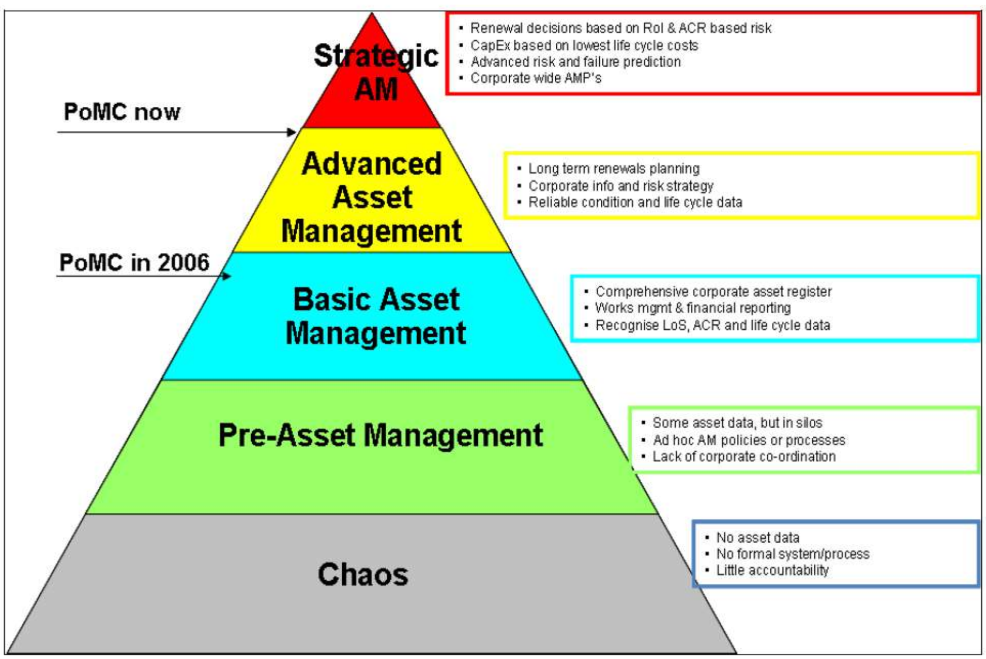


Fig. 3.10 Asset Management Maturity Model, Source: (Bianco, Giddings, 2010)

The PoMC set key benchmarks in order to achieve their improvement objectives of becoming a strategic asset management organisation, which can be summarised by four main processes and elements of functionality (Bianco, Giddings, 2010):

- Renewal Modelling
- Risk Management
- Optomised Renewals Decision Making
- Life Cycle Planning

Implementation of the Asset Management Plan & Strategy

The port's infrastructure portfolio is made up of the following major components:

- 34 commercial container, liquid bulk, breakbulk, and motor vehicle berths
- 7 kilometers of wharf length
- 35 major tenants
- 125 buildings
- 13.7 kilometers of roads
- 9.5 kilometers of rail
- Over 510 hectares of land
- Over 21 kilometers of waterfront and 100,000 Hectares of port waters (Bianco, Giddings, 2010)

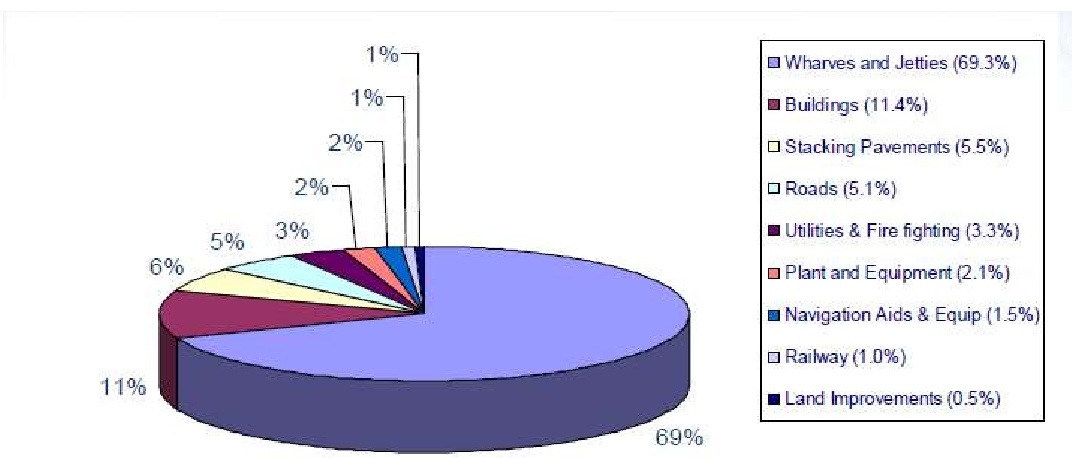


Fig.3.13 Port of Melbourne Corporation existing asset profile by asset value - Source (LoBianco, 2011)

The port invests significantly in the maintenance and rehabilitation of its waterways and infrastructure assets with the following investments into the infrastructure:

- The asset replacement cost: $1.3 billion

- Asset renewals, rehabilitation, and maintenance: $60–65 million (annual average)
- Maintenance dredging: $7 million per annum (including capping) (LoBianco, 2011)

Some of the port’s asset life extension techniques include:

- Wrapping of navigation beacons
- Pile repairs and wrapping
- Impressed current cathodic protection project at Swanson Dock
- Embedded anodes cathodic protection
- Sheet piling coated with sprayed concrete
- Road asphalt overlays (LoBianco, 2011)

The Port of Melbourne has also developed an integrated management system called the Compass, and this system delivers a documented and auditable approach to the port’s processes (Port of Melbourne, 2019). The Compass embodies a systematic and collaborative approach to designing, reviewing, and documenting the port’s critical business procedures and processes (Port of Melbourne, 2019). In March 2019, the port achieved ISO certification of the Compass with the following international Standards in March 2019:

- ISO 9001:2015 – Quality standard
- ISO 14001:2016 – Environmental standard
- ISO 45001:2018 - Occupational Health & Safety standard
- ISO 55001:2014 – Asset Management standard

The Compass delivers the following benefits for PoM and its customers and its stakeholders:

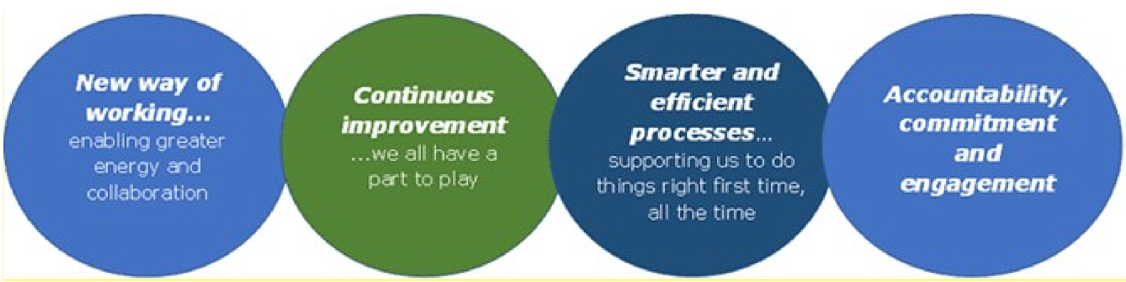


Fig.3.14 Benefits delivered by the Compass – Source: (Port of Melbourne, 2019)

Asset condition monitoring plays a very vital role in the Port of Melbourne's asset management strategy. Inspection and condition monitoring are undertaken periodically and are scheduled using a risk-based approach that considers aspects such as asset RUL and operational criticality. The inspections are key for the planning and prioritising of future maintenance budgets, and capital renewal works (Primmer, 2019).

Through regular inspections, potential issues with the assets are detected and corrected before they become major issues. With technological advancements, it has become possible to gather real-time data from monitoring assets using analytics to identify trends in the performance of assets (Primmer, 2019)

The PoM has developed an asset condition assessment methodology, and from figure 3.15 below, it can be seen that condition assessment is a key component of the asset management planning process. The assets' condition is visually assessed and ranked according to a scale based on visible defects. The condition data is essential for risk management, predictive modelling, rehabilitation and maintenance, valuation of assets, and budgeting (Sullivan & Rykers, 2010).

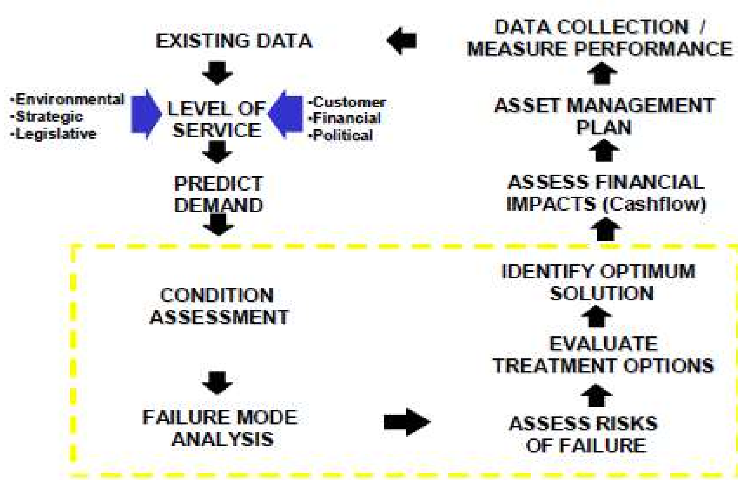


Fig.3.15 Asset Management Process Condition Manual – Source: (Sullivan & Rykers, 2010)

3.3.4 ASSET MANAGEMENT AT THE PORT OF ROTTERDAM

The Port of Rotterdam (POR) is the largest Port in Europe and is ranked ninth in the top 20 world ports, located in the City of Rotterdam, Netherlands (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017). The Port is the engine of the country's economy, with a total port area of 12 500ha. This Port employs over 180 000 people and contributes about 3.2% to the country's gross national product (GNP), which equates to € 21 billion.

It has a throughput of 461.2 million tons and 12.4 million TEU with an average water depth of 23 meters (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

The Port of Rotterdam has 32 asset types, with 70.5 km of concrete quay walls and jetties making up the majority of the asset base. The other asset types are roads, civil structures, buildings, and marine craft. The port has a maintenance budget of € 72 million and employs approximately 140 employees in the asset management department (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

Given a large amount of marine concrete infrastructure, the deterioration of infrastructure assets has tremendous impacts on the operations of the ports, and below are some of the issues that can be attributed to deterioration (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017):

- Deferred maintenance costs
- Inadequate Capital allocation
- Run-to-failure repair & maintenance programs
- Inspections done on random observations

This resulted in the loss of competitive edge and productivity as well as safety and security concerns (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

3.3.4.1 POR Asset Management

The POR regards asset management as a Strategic Imperative, and a process which forms part of the core functioning of the Port and has a slogan that says "Don't Plan Repairs. Predict Them" (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

The POR appreciates that the concrete waterfront structures like quays, jetties, and wharves are pivotal to operations of the organization, and as such, the income of the Port depends on the availability of the assets (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

The major consequences of the non-availability of assets to provide the required levels of service to customers could be loss of profit, which could decrease cash flow for the organization resulting in the inability to invest in the future (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

Another consequence would be the disruption to the tenants' business, which would be an undesirable situation for the Port to find itself in (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

3.3.4.2 The Objective of POR’s Asset Management Culture

To move away from being reactive and become more proactive by:

- Budgeting based on future needs as opposed to budgets based on previous years.
- Replacing high-risk assets before failure instead of reactive projects.
- Prioritising work based on risk instead of prioritising projects based on budget.
- Focusing on the high benefit to cost ratios, as opposed to investing funds with little risk reduction.

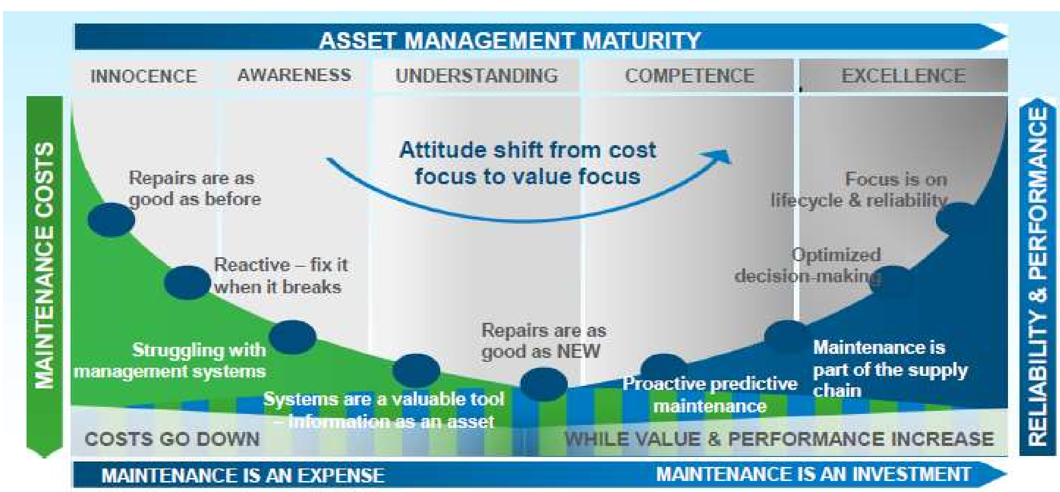


Fig 3.11 Asset Management Maturity: Source (Voogt, 2013)

3.3.4.3 The port of Rotterdam's Asset Management Programme stepstones are:

1. Document the assets owned and managed by POR
2. Understand the current condition of the assets
3. Understand budget requirements to catch up, keep up, and move forward.
4. Understand what endangers the functionality; risk analysis
5. Understand the business value, what is the contribution of the assets to the business goals.
6. Establishing the level of service for an asset and calculate the cost of the service
7. Prioritise the required budget based on risk and business value (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

The integration of smart computerised systems will aid asset management to create a master database, thereby making the asset management process more efficient and effective (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017). A centralised database will also enable asset owners', users, and those involved in the asset management process to have access to data at a few clicks of buttons (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

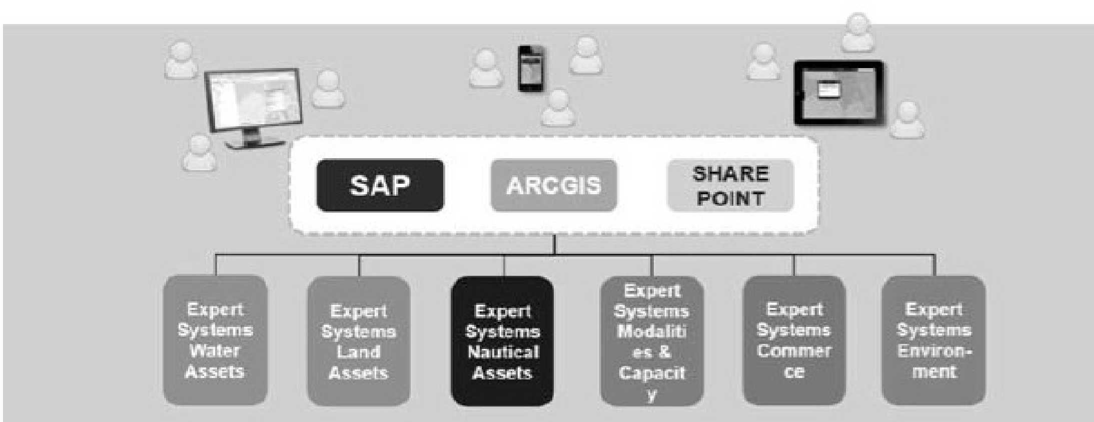


Fig. 3.12 Port Maps Architecture – Source: (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017)

The POR also makes use of smart systems as an asset management tool for modelling their concrete quay walls called KMS, a Dutch abbreviation for Quay wall Modelling System (Voogt, Port of Rotterdam's Road to World-Class Asset

Manangement, 2017). The modelling system uses the results of deterioration models for concrete and steel and compares it with the project delivery date. The system also identifies and ranks risks that pose a threat to the functionality of the structure (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017). KMS uses the business value of a concrete quay wall to simplify its maintenance priority.

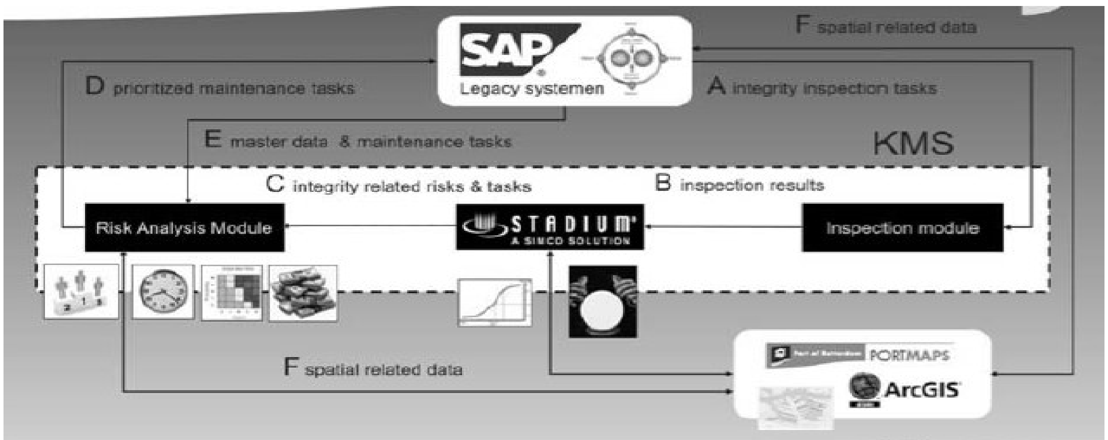


Fig. 3.13 Quay Wall Modelling System (KMS) – Source: (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017)

The Asset Management of POR's concrete Quay walls is essential to the organization as the largest asset type in its asset base. The remaining useful life and system integrity of quay walls are dependent on the quality of both the sub and superstructure (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017). The integrity of the quay can be compromised due to accelerated low water corrosion at the substructure of concrete deterioration in the superstructure (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

The KMS system, as depicted in Fig 3.13, incorporates integrity inspections, inspection results, integrity risks, prioritized maintenance, master data, and maintenance tasks (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017). The KMS, therefore, incorporates all the processes to manage a concrete quay wall.

The KMS has short to medium to long-term benefits, with the short-term benefit being transparent annual maintenance budgets. The mid-long term benefits are an insight into the remaining service life of the structures and the maintenance costs for each structure as well as insight on total port concrete costs (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017). The added benefits are the ability to conduct Just in Time inspections, proactive, prioritized, and risk-based maintenance, and most importantly, it contributes to huge cost savings (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017). The KMS also leads to a greater return on investment for the assets with approximately € 2.1 million in savings between inspections (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

With the dawn of the fourth industrial revolution and the digital age, organisations are relying more on smart IT solutions (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017). Through the deployment of smart, autonomous devices that are able to produce real-time information and share, it is enabling the port of Rotterdam to effectively control and manage its assets. An example is glass fibre sensors for the detection of piping effects on the quay walls (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

The POR's motto for their high-value concrete assets is "Proactive and Predictive Waterfront Asset Management, a Strategic Imperative for the Port of Rotterdam" (Voogt, Port of Rotterdam's Road to World-Class Asset Manangement, 2017).

Implementation of the Asset Management Plan & KMS

The port of Rotterdam has seen some great benefit from the development and implementation of the KMS software for the management of its quay walls, and they have also won some awards at the iMaintain Infrastructure Congress held in the Netherlands in 2012 as well as at the 2013 ACEC Engineering Excellence Awards held in New York (Voogt, 2013). This further reinforces the fact that technology is key in effectively managing strategic infrastructure by ensuring that effective maintenance and repair are done on marine infrastructure.

The design life of marine concrete structures is approximately about 50 years, and most of the port of Rotterdam's marine structures are approaching the end of their useful life. It was, therefore, essential that the port develops a system that would track required maintenance and assist in cost forecasts to keep the structures safe for service (SIMCO, 2020).

The KMS software is able to predict the basis of deterioration of materials making up the structure, and in the future, the prediction capability will be extended to quay wall furniture like the rubber for fenders (de Gijt, Louwen, & Voogt, 2016). This enables the port to make better decisions about which maintenance activities should be prioritized and when they should be executed as well as the frequency of inspection of quay walls. As indicated earlier in the paper, the quality of the quay wall superstructure and substructure are critical for the determination of the RUL of the structure, and with the aid of deterioration models, KMS is able to predict the lower safety limit for quay walls (de Gijt, Louwen, & Voogt, 2016). The software simulates maintenance strategies informed by inspection outcomes for effective management of the structures. The software also has some possible built-in risks that can negatively impact the quay walls. Insight into the dire consequences of postponement of maintenance activities as well as the advantages of different maintenance activities are provided by the KMS system (de Gijt, Louwen, & Voogt, 2016).

The port of Rotterdam understands the importance of Asset Management when it comes to the management of marine concrete structures, as 95% of these structures are submerged and makes them quite costly to maintain. According to De Gijt et al. (2016), the cost of maintenance is between 0,5% - 1,5% of the initial investment costs of the structure over its lifetime, which is similar to the costs indicated in Port Designers Handbooks, and the cost of demolition and disposal of quay walls costs can go up to 20% of the initial investment cost (de Gijt, Louwen, & Voogt, 2016).

3.3.5 ASSET MANAGEMENT AT TRANSNET NATIONAL PORTS AUTHORITY (TNPA)

Established through the National Ports Act, No 12 of 2005, Transnet National Ports Authority is the landlord of the ports and responsible for the safe, efficient, effective, and economic functioning of the national ports system on behalf of the government (Transnet National Ports Authority, 2018). TNPA has a number of core functions, as stipulated in section 11 of the Ports Act. The Infrastructure related core function of the TNPA is to plan, provide, maintain, and improve port infrastructure (Transnet National Ports Authority, 2018).

The ports utilises about 6000 ha of land area and comprise of approximately 30km of concrete quay walls in total across the ports, with plans for expansion of landside and quay wall infrastructure in the long-term (Transnet SOC, 2017). There are 127 berths across all ports, which translates to a throughput of over 160 million tons of cargo per annum (Transnet SOC, 2017). Break-bulk operations utilise the majority of the berths (42 berths), followed by dry bulk operations (30 berths), container operations (18 berths), and liquid bulk operations (16 berths) (Transnet SOC, 2017).

3.3.5.1 TNPA Port Asset Management and Systems

The Public Finance Management Act, No 1 of 1999 (PFMA) and the Government Immovable Asset Management Act No 19 of 2007, are the main guiding documents for the management of Transnet and TNPA port assets as a State-Owned Entity (SOE). Transnet Policies and Procedures on asset Management within Transnet are aligned to the aforementioned documents. There is no specific Transnet policy or standard that speaks specifically to Port Asset Management within TNPA. Like many other government entities, Transnet has traditionally used a more cash-based system for accounting, with the focus primarily being on deciding whether or not to fund new assets rather than measuring and deriving the most efficient benefit from the existing assets (North West Provincial Government, 2004). This approach tends to ignore or postpone maintenance requirements in favour of other pressing needs (North West Provincial Government, 2004).

An Asset Maintenance Principles & Procedures (AMPP) policy document was developed and endorsed in 2010 for the maintenance of port assets, of which the port engineering department is the custodian. It should be noted, however, that Asset Maintenance is only one aspect of the Asset Management process. The maintenance procedures in the AMPP are based on compliance with SABS standards, the OHS Act, British Standards, where a South African standard does not exist. OEM's maintenance manuals, expertise gained from experience, and lessons learnt are also an important part of the process (Mneney, Modipane, Nxumalo, & Bilse, 2015).

The Port Engineering department is responsible for the planning, condition assessment, budgeting, maintenance as well as the control of the budgets allocated for the maintenance of port infrastructure assets. The maintenance inspections and condition assessments are led by the Port Engineer or anyone delegated by the Port Engineer. The AMPP states that a series of procedures have to be followed to ensure that infrastructure assets are optimally maintained. TFR is Transnet's rail division and makes use of the Manual for Infrastructure Condition Assessment (MICA) document together with the Manual for Track Maintenance (MTM) for their inspections and condition assessment of their various infrastructure assets, including concrete structures. The MICA condition assessment forms are similar to the guidelines specified in the AMPP. In instances where TNPA and TFR infrastructure assets are in common areas like a bridge within the port, both responsible operating divisions of Transnet do the inspection process jointly, making use of either process documented in both the AMPP and the MICA, and MTM.

Table 3.4 Critical execution elements addressed during the course of executing maintenance – Source: (T Mneney, 2015)

Process Element	**Description / Steps**	**Outputs**	**Comments**
Regular or yearly Inspections	Assets inspected as prescribed. Actual & target conditions comparison. A decision on remedial action requirement. Sign requirements off after consultation with users.	Completed inspection form with entries. Completed preventive maintenance order detailing inspection and asset inspected.	Some inspection intervals may be more frequent. The critical works could be done in the current year. All assets requiring inspections must have an appropriate maintenance plan.
Determination of the amount of work	Physical work requirements assessment. Description of job elements. Consultation with regulatory departments, i.e., environmental to determine requirements.	Tasks listed per asset.	

	Leased assets maintenance requirements sent to the Property Manager.		
Planning	Resource requirements are determined. Prioritisation of tasks. Obtain occupations inputs as well as user requirements. Amendment of personnel structure, if required.	A prioritised list of jobs.	
Costing	Determine the cost of job per resource requirements	a prioritised list of jobs with cost per resource (labour, material, plant, contract, other)	
Budgeting	Prepare an outline schedule for all jobs. Calculate cash flow per job. Summarise job cash flows to get total cash flow. Enter into the system according to budget guidelines. Obtain approval / amend using priority list as a guide if required.	Draft maintenance schedule. Monthly cash flow. Approved budget.	
Organisation	Prepare the final schedule. Implement personnel structure.		
Execution	Procure resources according to schedule. Carry out work. Monitor quality, legal compliance, progress, and spending and take	Transfer approved maintenance schedule into SAP by way of maintenance plans and detailed task lists. Schedule approved maintenance plans.	

	appropriate action as required. Enter the relevant information into SAP.	Process released maintenance orders to completion	
Audit	Regular inspections of processes and assets Monitor progress on SAP system	Call Business Warehouse (BW) and SAP PMIS reports	

Stakeholder involvement is critical to the planning process for maintenance to minimise disruptions to operations (Mneney, Modipane, Nxumalo, & Bilse, 2015). TNPA also performs oversight functions for assets leased to third parties within the port.

The CMMS computer software used by Transnet to streamline maintenance management is SAP, which is also used by the financial management department and the supply chain department in line with the Public Finance Management Act (PFMA). The finance department is the custodian of the Fixed Asset Register (FAR) and is responsible for managing the process to keep this register up to date. The Port Engineer ensures alignment between the FAR and the SAP master data. The Maintenance Manager must ensure that maintenance regimes are created on SAP PM for all maintainable assets (Mneney, Modipane, Nxumalo, & Bilse, 2015).

Inspections on assets should be done in accordance with the Original Equipment Manufacturer (OEM), as well as Transnet codes of practice and inspection frequencies loaded onto SAP through detailed lists of tasks in the maintenance plans (Mneney, Modipane, Nxumalo, & Bilse, 2015). Asset condition monitoring schedules must be integrated with the SAP PM system to enable the overall condition of assets in ports to be displayed by the system. Remaining Useful Life (RUL) forms part of the asset condition monitoring (Mneney, Modipane, Nxumalo, & Bilse, 2015).

TNPA's AMPP stipulates that budgets for the operating functions are performed in strict accordance with the Finance Department guidance. There is generally a zero-budget rule for planned maintenance. Life Cycle Costing considers the total asset cost from conception to disposal. It is, therefore, important that life cycle costing

principles be applied from the conceptual design stage (Mneney, Modipane, Nxumalo, & Bilse, 2015).
Because the capital investment associated with the construction and operation of a marine structure is high, it necessitates the selection of the most economical structure for projects wherever possible (PRDW, 2015). A holistic, long-term view needs to be considered taking into account the total performance of the structure during its lifespan, meaning that the total life-cycle cost (LCC) of the structure should be considered, and not just the construction cost (PRDW, 2015). These costs include: preliminary, pre-feasibility, and feasibility work costs; design costs; construction costs; inspection, maintenance and rehabilitation costs; repair costs; renewal and/or modification costs; disposal costs; indirect costs such as loss of revenue during periods of non-availability (PRDW, 2015). These costs are incurred at different times during the lifetime of a structure and for comparative purposes; these costs must be converted to a common measure; usually, the net present value (NPV), taking into account the variation of the value of money over time (PRDW, 2015).

The expected future life of assets is vital for TNPA since their value is lodged in TNPA's asset base, which comprises mainly of concrete Infrastructure, Marine, Dredging, and Lighthouse assets. The determination of the Remaining Useful Life (RUL) of assets is not only important for planning operational utilization (capacity planning), the prediction of future operational/ capital spending but also for determination of depreciation (Mneney, Modipane, Nxumalo, & Bilse, 2015).

The Port Engineer and his staff need to ensure that risk assessments are conducted on all assets for maintenance work and ensure alignment with Transnet's Risk Assessment System (CURA**)** (Mneney, Modipane, Nxumalo, & Bilse, 2015)**.** A risk treatment plan needs to be developed to reduce or mitigate the risks. Use of SAP PM permit system assigned either to technical objects or maintenance orders must be adhered to in instances where safety or work conditions are required before work is commenced or on work completion. In the event, an asset is unsafe, defective, or in a state of disrepair, maintenance teams must issue a stop certificate and inform the relevant Parties (Mneney, Modipane, Nxumalo, & Bilse, 2015).

3.3.5.2 Quays and other Berthing Structures (Wet Assets)

The TNPA AMPP manual states that quay walls, jetties, and dolphins are the primary interface between the water and land. Quay walls constructed in South Africa generally consist of caisson walls, block-walls, steel sheet pile walls, deck on pile walls, and counter-fort walls. Jetties usually consist of a deck on pile structures constructed perpendicular to the land. Dolphins generally consist of caissons, blockwork, concrete deck on piles (Mneney, Modipane, Nxumalo, & Bilse, 2015).

The AMPP document gives guidance for inspections and maintenance planning/execution of quays, jetties, and dolphins based on some of the current best practices in the ports. The Guide is in line with all the relevant policies and legal requirements, which are, construction Regulations Act, OHS act, water quality, and TNPA Environmental Policy (Mneney, Modipane, Nxumalo, & Bilse, 2015).

The AMPP further goes on to specify the types of inspections done for quays, jetties, dolphins and the three main types used by the ports are; Eyeball (structure above water), diving, Non-destructive Testing (NDT) (Instrument measure). The eyeball method is a visual inspection of the structure on a routine basis. The AMMP prescribes that the eyeball inspections be carried out at least once a year, depending on the requirements of the ports, preferably during the low spring tides. A general walk-about and careful visual inspection of the structure and various associated elements are done (Mneney, Modipane, Nxumalo, & Bilse, 2015). The findings of the visual inspection such as damage or concerns, for example, cracks, settlements behind the quay, are then recorded, and action should be taken immediately should there be a need for further detailed investigations and/or repair (Mneney, Modipane, Nxumalo, & Bilse, 2015).

General aspects/items to consider in inspections are cope-line levels (an indication of settlements); Signs of cracks; severe spalling; Drainage; Surfacing; Services (tunnel); bollards; Fenders, and access ladders (Mneney, Modipane, Nxumalo, & Bilse, 2015).

It is considered best practice that NDT methods are performed after the eyeball inspections to further evaluate the condition of the structures should there be visible signs of deterioration. The NDT methods are of great value in assessing the current state of reinforced concrete assets, such as marine concrete structures, bridges, reservoirs, concrete pavements, and quays. The primary objective of NDT of concrete structures is to determine and assess the in-situ strength, durability, density, moisture content, elastic properties, and visible cracks (Mneney, Modipane, Nxumalo, & Bilse, 2015).

In 2008, TNPA sought the services of consultants and naval architects to assist in developing an optimal method for determining the Remaining Useful Life (RUL) of their wet assets (Mneney, Modipane, Nxumalo, & Bilse, 2015). One of the recommendations was for TNPA to develop an Asset Management Framework for all their (class 41) wet assets, i.e., structures exposed to the seawater as indicated in the fig. 3.14 below (Mneney, Modipane, Nxumalo, & Bilse, 2015).

Current Condition of Port structures

For the TNPA ports the Asset Maintenance Procedures & Principles (AMPP) guide is utilised in all of the ports, and the ports also make use of the SAP system for their maintenance planning and budgeting and recording of asset condition. There is alignment between the Finance department who are responsible for the Fixed Asset Register (FAR) and the Port Engineer's office who is responsible for the maintenance, repairs and upgrade of the marine concrete assets as well as all other assets in the port. The Port Engineer also plays an oversight role together with the Real Estate department for all leased infrastructure assets.

There are annual asset condition inspections conducted throughout the port system and coordinated through the Chief Engineers office to ensure standardization in terms of conducting of asset condition inspections, reporting as well as repair strategies where required.

Most of the older ports have visibly deteriorated marine structures which have long exceeded the RUL's, with some Alkali Aggregate Reaction (ARR) evidence and the most prevalent reinforcement corrosion as the main form of deterioration due to chloride intrusion due to the environment that the structures exist. The condition of the structures can be attributed to deferred maintenance budgets over the years as well as due to most of the structures having exceeded their design lives. There are numerous asset renewal projects planned and in implementation stage to upgrade and extend the remaining useful life of most reinforced concrete structures exposed to the harsh marine environment. There is need for a dedicated drive to catch up on the backlogs for critical maintenance of marine structures.

There are annual asset condition inspections which are conducted and coordinated through the Chief Engineers office. From these inspections the asset condition is recorded, and maintenance budgets are derived and the assessment on the previously identified maintenance requirements and the progress thereof is also done.

The frequency of these inspections is not adequate as the ports should conduct inspections quarterly or at least biannually to properly monitor the condition and progress of recommended maintenance repairs. The NDT methods are not used unless there is a major repairs project to be done and as a result there is a strong reliance on the eyeball method for inspection and condition assessment.

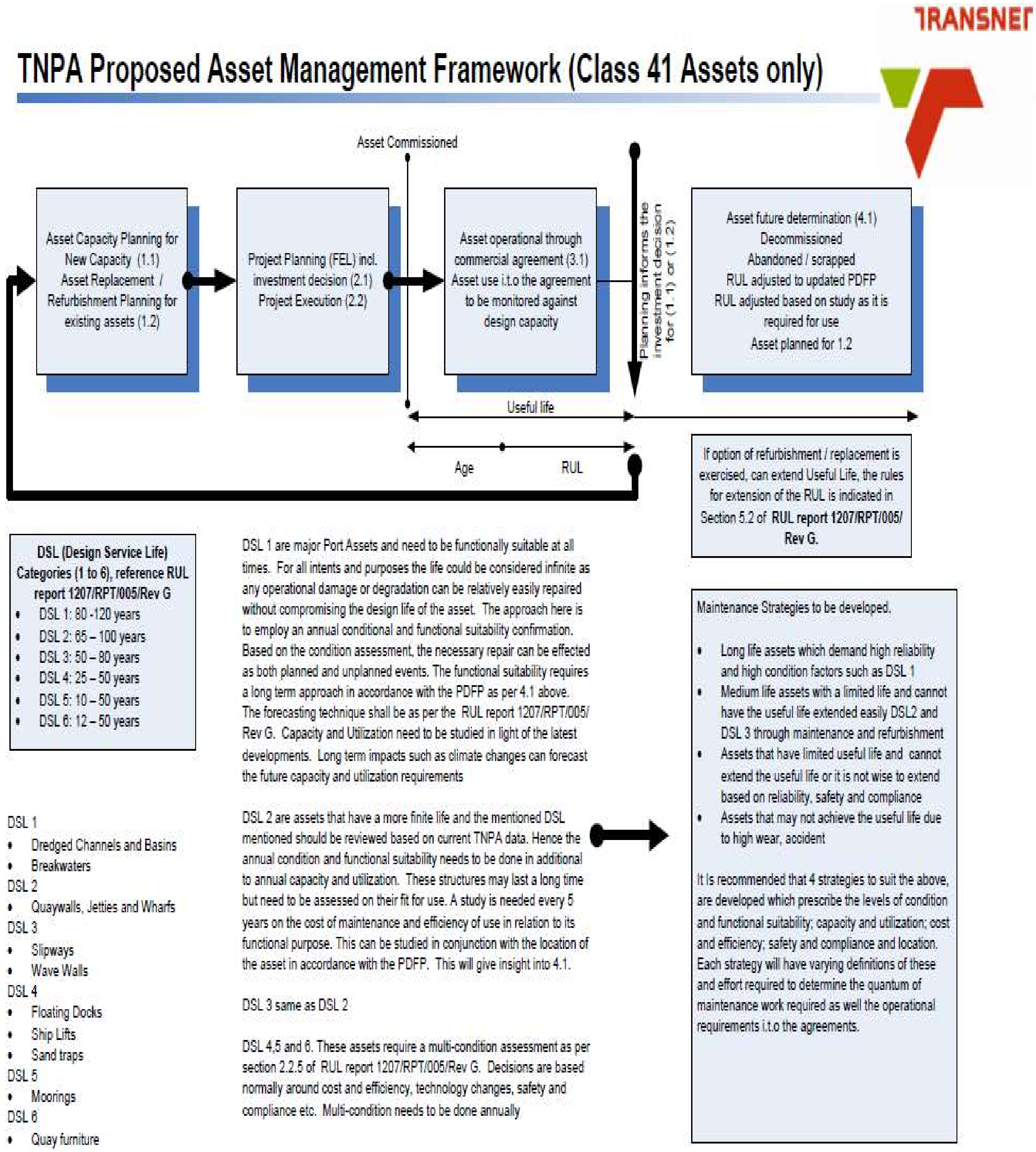


Fig 3.14 Proposed TNPA Asset Management Framework - Source: (T Mneney, 2015)

4. CHAPTER 4

4.1 CRITICAL REVIEW OF TNPA'S IAM SYSTEMS

The TNPA has some very good processes for the maintenance of its infrastructure assets, and these are aligned with industry best practices. An Asset Management Framework does not exist for TNPA concrete assets or any other assets for that matter. There is also very little evidence of one for other Transnet Operating divisions. There is a proposed Asset management framework, which is centered on the determination of the remaining useful life of assets, as indicated in Fig 3.13 in the previous chapter. The proposed framework also lacks some other critical elements of an asset management Framework. The AMPP philosophy focuses on the maintenance of infrastructure assets and is not fully encompassing of the asset management processes.

Asset Management, according to the PFMA, is more focused / centered on the financial aspect of assets and places the responsibility on the accounting officer as outlined in section 38 of the PFMA on the accounting officer for the financial, risk management as well as the efficient use of the assets and resources (North West Provincial Government, 2004). The Accounting officer is also responsible for the management, maintenance of assets, and the management of liabilities. It is there clear that the PFMA places great emphasis on the accounting officer for the management and accounting of assets. The process involves the compilation of asset registers, validation of their completeness as well as Asset Life Cycle Management (North West Provincial Government, 2004). It is clear from the above that the PFMA covers assets more from an accounting and financial aspect; however, the aspects of condition assessment, levels of services provided by assets, risk management, and long-term asset planning do not come through. The asset registers should contain more historical data on the assets and not only the current value of the assets. It is also clear that financial accounting is not an end in itself and other measures of asset performance such as functionality and utilisation need to also be managed. The Asset Life Cycle Management should also involve more than just the accounting aspect of the asset management process (North West Provincial Government, 2004).

There are some elements of asset management functions within TNPA processes; however, there is a need for a properly structured asset management framework, which encompasses all aspects of the Asset Management process. The TNPA is also not certified with any asset management body like PAS 55, ISO 55000, and ISO 55001 or the SANS 55000 & 55001, which are the South African equivalent of ISO standards. There is an urgent need for the development of an asset management system that is aligned to ISO 55000 and ISO 55001 as well as certification with ISO in order to have an asset management system aligned to industry best practices.

There are annual AMPP inspections conducted on the entire TNPA infrastructure in conjunction with the Chief Engineer's office. The inspections include an assessment of all Civil, Electrical, and Mechanical infrastructure; however, as indicated in previous chapters, the focus of this dissertation is on the existing marine concrete structures. The author is of the view that the shortcoming of the inspections is that they are limited to visual assessments, and this requires trained and experienced personnel and, in most cases, inexperienced Engineers and Technicians conduct these inspections. The ports also do not own any NDT equipment for proper assessment of the asset condition of visibly deteriorating structures and place greater reliance on the visual inspections. There is no asset risk rating system, except for the asset registers, which are largely financially focused. There is no systematic approach to life cycle management, determination of the RUL taking into account all relevant factors is still to be undertaken, determination of port capacity with respect to RUL of assets, the consideration of RUL in the determination of future capacity and CAPEX requirements, and a maintenance strategy for RUL of assets (T Mneney, 2015).

It should also be noted that even though SAP is used as a smart system for asset management and maintenance, the function is currently from a financial management aspect, and there needs to be a more integrated system with other smart systems, which aid the asset management process. There is also a lack of smart modelling systems to better assess asset integrity, identify risks, and assist the port in adopting a more proactive approach. The allocation and availability of budgets to conduct required maintenance appear to be a challenge throughout the ports. Even though budgets are allocated, ports are unable to spend due to various factors, with reactive maintenance being one of the reasons. The frequency at which the maintenance and repairs are done in relation to the inspection reports is an area that can be improved upon, especially in the older ports with aging infrastructure. There are many factors that may affect the successful implementation of the maintenance plans, and these include but are not limited to governance processes, availability of the required skill sets to execute the tasks, procurement processes, and availability of budgets.

It is not all doom and gloom for the Transnet's NPA because as much as there are shortcomings and an absence of a structured Asset Management System, there are notable efforts that have been made to ensure that the infrastructure is in a well maintained and safe condition to continue to render the service currently offered by TNPA. According to the SAICE Infrastructure Report Card (IRC), the TNPA commercial Ports have also shown a slight improvement from the 2006 report, which saw them move from a C+ to a B- and maintained the B- score in the 2017 report with some positive criticism but in general a positive outlook for the South African Commercial Ports (SAICE, 2017). The last SAICE IRC shows that even though much of the existing infrastructure is aging, TNPA has continued to make a concerted effort to repair and maintain its equipment and infrastructure, keeping it operationally serviceable. As demand and congestion increases in most of the ports, both the fixed and movable infrastructure still performs well in meeting the safety and operational standards (SAICE, 2017).

5. CHAPTER 5

5.1 CONCLUSION

The objective of this dissertation was to determine if the TNPA had an Asset Management System or Framework and to examine the current maintenance procedures or systems for port concrete structures within TNPA in comparison to industry best practices. The intention was not to do a comparison exercise but rather to look for alignment and similarities, as different ports and countries around the world have their own unique social, economic, and political dynamics. The main outcome of the dissertation established that an Asset Management system for TNPA's core concrete assets is non – existent. The TNPA is not certified with any Infrastructure Asset Management body like ISO 550001, which is a critical shortcoming that needs to be addressed as soon as possible. However, TPNA does have in place aspects of asset management as prescribed by the PFMA, such as the creation of asset registers, value assessments of the assets through their lifecycle, the planning and budgeting of maintenance, and Capital replacement budgeting. However, these are all more financially focused from an accounting perspective and can be improved upon with the development of an Asset Management Framework and systems informed by ISO guidelines. The use of smart technology capable of integration with existing computer systems currently in place, like SAP, will be highly advantageous in providing a database of information on all assets.

Another finding from the research was that there are maintenance processes of a high standard on par with most international ports; however, they are not fully encompassed in an asset management framework. There is an opportunity for the TNPA to benchmark the international ports that have asset management systems in place and implement a strategic asset management framework. It can also be seen from the AMPP that budgets are prepared for repairs and maintenance; however, the infrastructure teams either fail to utilise the allocated budgets or fail to secure the required budgets due to various reasons, which in turn cause required maintenance and repairs to be deferred.

The TNPA infrastructure teams are aware of the need to design more durable and reliable structures with repair and maintenance schedules and taking into consideration how associated costs are allocated during the intended lifetime of the structure, i.e., Life Cycle Costing (LCC) as this plays an important role in the decision making process for the Port. It has also become clearer to the engineering teams that the lowest capital costs for structures are not always the lowest solution over the lifetime of the structures. The operational costs of concrete structures, and especially marine concrete structures, should be considered from the conceptual and design stages of projects. One such Port is the newer Port of Ngqura, which has some excellent types of concrete structures and incorporates various durability aspects to minimize effects from their exposure to the marine environment.

5.2 RECOMMENDATIONS

There are numerous international standards and guidelines for Infrastructure Asset Management like PAS 55, ISO 55000, and bodies like IIMM and GFMAM that can be utilised to assist in the development of an asset management framework for TNPA. Transnet should consider certification with ISO for asset management and maintenance and integrate the current AMPP document into the Asset Management Framework. TNPA's asset management teams should adopt a risk-based approach and utilise a ranking system for the critical assets as well as the consequences associated with not managing and maintaining the structures. TNPA should strive towards adopting a proactive approach to maintenance as opposed to a reactive one.

The TNPA already has partnerships with other international ports and is affiliated to PIANC. These relationships should also be utilised when developing an Asset Management Framework. There is also an opportunity for a case study to be conducted on TNPA's road to developing an Asset Management Framework Plan.

Quay wall structures are generally designed for a minimum life of 25 – 50 years (PIANC, 2008) and should be designed to be more flexible with longer design life to enable the structures to be adapted for different uses over their lifetime (PIANC, 2008). Implementation of Life Cycle Management (LCM) should be done in the following three-steps, once the functional requirements and design criteria are known:

- Identify alternatives
- Estimate the associated costs and benefits
- Apply whole life costing to aid decision-making (PIANC, 2008)

The three steps for implementing LCM are further explained in figure 5.1.

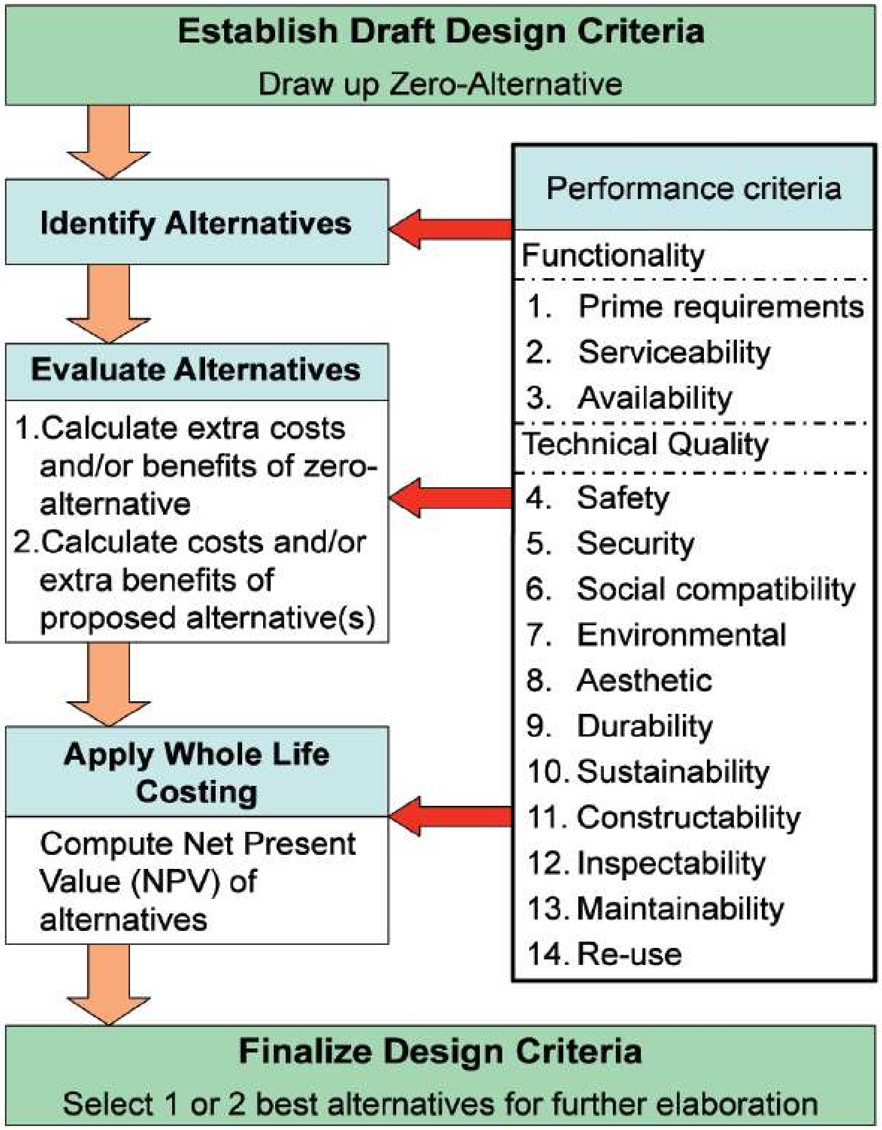


Figure 5.1: The LCM procedure – Source: (PIANC, 2008)

The following recommendations proposed by the ZLH report produced for the TNPA in 2008 need to be considered and used as a starting point for the development of an asset management framework for TNPA's wet assets (T Mneney, 2015)

- The report produced in 2008 is to be used as the basis for the determination of the RUL for TNPA Wet Assets (class 41)

- The Design Service Life for the various assets types must be reassessed by TNPA, and maintenance strategies for the various assets types must be developed
- An Asset Management Framework must be developed and implemented
- Commence with detailed inspections and prepare estimates for RUL for port infrastructure class 41 assets (T Mneney, 2015, pp. 157-158).

There are five asset management principles recommended from the KwaZulu-Natal Provincial Treasury Instruction Note No. 30: Movable Asset Management (KwaZulu-Natal Provincial Treasury, 2013).

- The level of service requirements is to guide asset practices and decisions.
- Asset planning and management to be integrated with strategic business plans, budgetary, and reporting processes.
- Asset management decisions to be based on evaluations of alternatives that take into account full life cycle costs, benefits, and risks of assets.
- Ownership, control, accountability, and reporting requirements for assets are to be established, clearly communicated, and implemented.
- Asset management activities are to be undertaken within an integrated Government asset management policy framework (KwaZulu-Natal Provincial Treasury, 2013, pp. 4-6)

An article by Ron Moore gives a guide to developing an effective asset management strategy which the TNPA could adopt (Moore, 2014). It states the following:

- An asset management strategy should begin with the needs of the organization and should be aligned with the strategy of the organization. Business requirements for the assets should be clearly defined.
- Current asset performance should be measured against asset requirements. A gap analysis should be done accompanied by plans to improve the current performance. Efficient & reliable performance from existing assets must be assured prior to authorizing additional capital for additional capacity.
- Lifecycle cost and performance implications principles should be applied in the planning and design of new capital projects.

- Operations departments should exercise strong leadership when managing assets.
- Kaizen, total productive maintenance, RCM, and root-cause analysis are useful tools to manage asset performance. Condition monitoring for physical assets requires priority.
- Executives and management must take a leading role in developing the asset management strategy for the organization, ensuring alignment with organizational needs. Upon approval of the asset management plan by the executives, they have an obligation to support it.
- There should be cross-departmental and divisional partnerships formed with clear parameters on how they interface and support each other.
- People should be viewed as the most valuable asset of an organization; as such, they should be trained, developed, and made capable (Moore, 2014).

There is also an opportunity to incorporate measures to address climate change effects in the design of new assets as well as the existing assets during the development of an Asset Management Framework by TNPA.

The implementation of smart technologies for monitoring, modelling, and identifying risks for the assets and the business should be prioritised. Smart technologies should be capable of fully integrating with the existing SAP system in place.

6. REFERENCES

(CIDB), C. I. (2007, July). *National Infrastructure Maintenance Strategy (NIMS): in support of ASGISA and government growth objectives.* Retrieved from CIDB - development through partnership: http://www.cidb.org.za/publications/Documents/National%20Infrastructure%20Maintenance%20Strategy.pdf

(NAMS). (2011). *International Infrastructure Management Manual IIMM.* Retrieved November 13, 2017, from National Asset Management Support Group.

(NAMS), N. A. (2011). *International Infrastructure Management Manual IIMM.* Retrieved November 13, 2017

(NAMS), N. Z. (2014). *Supplement to the IIMM 2011: Quick Guide to Meeting ISO 55001 Requirements.* New Zealand: New Zealand National Asset Management Support Group (NAMS) and the Institute of Public Works.

A Ramamurthy, R. N. (2016). ISO 55000 and Asset Management - 5W's. Boston: NEWEA.

Affairs, O. P.-D. (2016). *South Africa's - OCEANS ECONOMY.* Johannesburg: Department of Environmental Affairs.

Africa, P. &. (n.d.). *East London*. Retrieved July 09, 2018, from http://ports.co.za/east-london.php

Africa, P. a.-s. (2017, October 28). *Port of Durban*. Retrieved July 18, 2018, from Ports and Ships - shipping and harbour news out of Africa: https://ports.co.za/durban-harbour.php

Africa, T. &. (n.d.). *Port of Durban*. Retrieved September 7, 2018, from https://ports.co.za/durban-harbour.php

Africa.com, S. (n.d.). *South Africa.com*. Retrieved from Port of East London: https://www.southafrica.com/regions/ports/port-of-east-london/

African, D. R. (2010, October 08). *Port Development in Africa.* Retrieved September 03, 2018, from https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/African%20Development%20Report%202010_CH%202.pdf

Allianz Global, C. (2016). ARC Marine – Marine Port Structure Guidance. *Allianz Global Corporate & Specialty White Paper*, 12. Retrieved August 31, 2017

Amarra, F. (2015, September 18). *KBC IoE Webinar - ISO 55000 - Asset Management.* Retrieved from Linkedin SlideShare - by LinkedIn Learning: https://www.slideshare.net/kbc_at/kbc-ioe-webinar-iso-55000-asset-management

Australasia, C. o.-T. (2017, February). *Bridges Asset Management Plan (2017).* Retrieved October 11, 2018, from https://www.charlessturt.sa.gov.au/webdata/resources/minutesAgendas/Item%203.10%20-%20Presentation

Authority, T. N. (2010). *Port of Ngqura*. Retrieved July 09, 2018, from https://www.transnetnationalportsauthority.net/OurPorts/Ngqura/Pages/Overview.aspx

Authority, T. N. (n.d.). *Transnet National Ports Authority.net.* Retrieved from Port of Ngqura: https://www.transnetnationalportsauthority.net/OurPorts/Ngqura/Pages/Overview.aspx

Bastidas-Arteaga, E. (2016). Reliability of Reinforced Concrete Structures Subjected to Corrosion-Fatigue and Climate Change. *International Journal of Concrete Structures and Materials*, 13.

Berning, M. (2018). *Construction of Marine Infrastructure in the Port of Richardsbay.* Richardsbay: Transnet National Ports Authority.

Beushausen, H. (2015). *Concrete Deterioration CIV5116Z.* Cape Town: University of Cape Town.

BG&E. (2018, September 19). *Asset Management Capability - BG&E.* Retrieved December 01, 2018, from https://www.bgeeng.com/bge-capabilities/asset-management/2/

BG&E Asset Management. (2018, September 19). *Asset Management Capability - BG&E.* Retrieved December 01, 2018, from https://www.bgeeng.com/bge-capabilities/asset-management/2/

Bianco, Giddings, D. (2010). Strategic Asset Management at the Port of Melbourne. *PIANC MMX Congress Liverpool UK 2010* (p. 11). Liverpool: Port of Melbourne Corporation.

Birtig, T. (2015, March 19). *City of Powell River.* Retrieved from City of Powell River Asset Management Program:

https://www.ubcm.ca/assets/Funding~Programs/Asset~Management/Powell%20River%20Case%20Study.pdf

Bonte, P. (2007). Structural design of a sandwich wall as the quay wall for the future "An investigation to apply parametric design to quay wall structures". DELT: Delta Marine Consultants & TU DELFT.

Boshoff, L. (2016). *Cities' Infrastructure Delivery and Management Systems (CIDMS) - International and National Underpinning of CIDMS.* Cape Town: IAT Consulting.

Boshoff, L. (2016, June 7). International and National Underpinning of CIDMS. *Cities Infrastructure Delivery and Management System - CIDMS*, pp. 1-69.

Brown, S. (1994). Port Engineering Handbook - Chief Engineers Section, Portnet, Johannesburg. *Portnet, 1*(1), 250.

BSI, S. (2012, February 26). *Asset management — Overview, principles and terminology - ISO/CD 55000.2.* London: British Standards Institution.

Bullimore, K. (2015). *Maintenance Strategy 2015.* Retrieved from The Open University: http:/www.open.ac.uk

Chandrasekhar, M. (2009). Port Infrastructure Development - Opportunities in these Challenging Times. Boston: Halcrow, Inc.

City of Powell River. (2013). *City of Powell River - Marine Asset Management Plan.* POWELL RIVER.

City of Powell River. (2014, January). *City of Powell River.* Retrieved from CITY OF POWELL RIVER – ASSET MANAGEMENT STRATEGY: https://powellriver.civicweb.net/document/24122

Council, M. (2012). *Asset Management Marine Structures* (1 ed.). SIDNEY: Opus International Consultants.

D Phelp, M. R. (2013). Potential Impacts of Climate Change on South African Ports and Coast. Brussels: CSIR.

Dasgupta, S. (2013, April 26). *Marine Ports*. Retrieved from Marine Insight: https://www.marineinsight.com/ports/what-are-the-various-types-of-ports/amp/

de Gijt, J., Louwen, A., & Voogt, H. (2016). Implementation of life cycle costing in port infrastructure. *The Fifth International Symposium on Life-Cycle Engineering (IALCCE 2016)* (p. 6). Delt: CRC Press.

Dietrich, N. (2015, December 10). *Back to Basics: What is Infrastructure Asset Management?* Retrieved August 08, 2018, from IQMS: https://www.imqs.co.za/news-articles/asset-management/what-is-infrastructure-asset-management/

Dietrich, N. (2018, May 30). *BACK TO BASICS: WHAT IS INFRASTRUCTURE ASSET MANAGEMENT?* Retrieved from IMQS: https://www.imqs.co.za/news-articles/asset-management/what-is-infrastructure-asset-management/

Duvenage, P. (2015, March). Developing a Method for Prioritising Maintenance for Reinforced Concrete Reservoirs. Stellenbosch: University of Stellenbosch. Retrieved July 25, 2018

e-Magazine, R. H. (2007). *Basic Steps of Applying Reliability Centered Maintenance (RCM) Part III*. Retrieved September 09, 2017, from https://www.weibull.com/hotwire/issue76/relbasics76.htm

Environmental Protection Agency, I. (2019, July 24). *Communicating Climate Science.* Retrieved from Environmental Protection Agency: https://www.epa.ie/climate/communicatingclimatescience/whatisclimatechange/

Finder, V. (n.d.). *East London, South Africa.* Retrieved October 01, 2018, from https://www.vesselfinder.com/ports/EAST-LONDON-SOUTH-AFRICA-1069

Fisk, G. (2017). *Climate Risks and Adaptation Pathways for Coastal Transport Infrastructure - Guidelines for Planning and Adaptive Responses.* Gold Coast - Australia: National Climate Change Adaptation Research Facility 2017.

Gambit, W. a. (n.d.). *Mossel Bay - Africa Ports*. Retrieved September 7, 2018, from https://africaports.co.za/mossel-bay/

Giddings, D. (. (2010). *STRATEGIC ASSET MANAGEMENT AT THE PORT OF MELBOURNE.* LIVERPOOL: PIANC.

Gijt, J. G. (2010). A History of Quay Walls - Techniques, types, costs & Future. Delft, Netherlands: TU DELFT.

Grotheer, W. (2007, November 07). *Developing an Asset Management Framework.* Retrieved from Port of Seatle: http://www.onlinepubs.trb.org/onlinepubs/archive/conference/2007/asset/20_Groother.pdf

H W Rothman, J. v. (2010). *Maintenance Engineering: Manual for Infrastructure Condition Assessment (MICA).* JOHANNESBURG: TRANSNET FREIGHT RAIL.

Heathcote, J. (2015). Extending the benefits life cycle: ISO55000. London: Association for Project Management.

Heisler, R. (2014, July 09). *Life Cycle Engineering - Overview of ISO 55000.* Retrieved August 21, 2017, from https://www.slideshare.net/LifeCycleEngineering/iso-55000-overview

Hilton, T. (2009, September 2015). *Port Elizabeth Harbour (1958) - Flickr.* Retrieved October 01, 2018, from https://www.flickr.com/photos/hilton-t/3953229760/

Howard, S. (1936). *South Africa's Eastern Port*. Retrieved September 7, 2018, from Facts about Durban: https://www.fad.co.za/Resources/bay/bay.htm

info, S. (2007 , December). *South Africa's two Ocean currents* -.

Ingpen, B. (2015). *The history of Cape Town harbour | Maritime Economics SA Grade 10*. Retrieved September 04, 2018, from Maritime Studies - South Africa : http://maritimesa.org/grade-10/the-history-of-cape-town-harbour/

Ingpen, B. (2015). *Maritime Studies - South Africa - Ocean Currents | Maritime Economics SA Grade 10*. Retrieved September 6, 2018, from http://maritimesa.org/grade-10/ocean-currents/

Isaacs, B. (2015). *SERVICE LIFE OF CONCRETE INFRASTRUCTURE IN THE SOUTH AFRICAN MARINE ENVIRONMENT.* Cape Town: University of Cape Town.

ISO/PC 251, A. m. (2014, January 15). *ISO 55001.* Retrieved August 26, 2017, from https://www.iso.org/files/live/sites/isoorg/files/archive/pdf/en/iso-55089-colour_pdf.pdf

ISO/PC 251, Asset management. (2014, January 15). *ISO 55001 - Asset Mananagement System Requirements.* Retrieved from ISO (The International Organization for Standardisation): https://www.iso.org/files/live/sites/isoorg/files/archive/pdf/en/iso-55089-colour_pdf.pdf

Jarit DE GIJT, R. V. (2011). Cost of quay walls including life cycle aspects. *International Maritime-Port Technology and Development Conference (MTEC 2011), 1*, 1-5.

Josiah Mpofu. (2016). *Critical Assets, Risk and Decision Making.* Cape Town: University of Cape Town.

Joubert, F. (2016). *Advanced Infrastructure Management.* Cape Town: University of Cape Town.

K Modipane, S. N. (2016). *Engineering: Asset Maintenance Priciples and Procedures.* Johannesburg: Transnet National Ports Authority.

Kovacevic, J. (2016). *HP Reliability, Erudito*. Retrieved January 18, 2019, from http://www.hpreliability.com

Kremlin, D. (2015, July 03). *The South African Air force: Oil Tankers South Africa.* Retrieved September 09, 2018, from http://www.saairforce.co.za/forum/viewtopic.php?t=8235

KwaZulu-Natal Provincial Treasury. (2013, April 01). *Asset Management Framework - KZN Treasury.* Retrieved from KwaZulu-Natal Provincial Treasury: https://kzntreasury.gov.za/Instruction%20Notes/pt-instruction-note-no-30-movable-asset-management.pdf

L Kasekende, M. N. (2010). *AFRICAN DEVELOPMENT REPORT 2010 - CH 2 Port Development in Africa.* NEW YORK: THE AFRICAN DEVELOPMENT BANK - OXFORD UNIVERSITY PRESS.

Li, L. S. (2007). Reliability Based Asset Management Strategy for Concrete Infrastructure. *International Journal of Materials & Structural Reliability, 5*(1), 13-28.

Life Cycle Engineering, I. -R. (2015). *Life Cycle Asset Management.* Retrieved November 22, 2018, from https://www.lce.com/Life-Cycle-Asset-Management-1112.html

LoBianco, D. (. (2011, August 10). Retrieved from Strategic Asset Management atthe Port of Melbourne: https://www.aapa-ports.org/files/PDFs/PPT%20Slides%20on%20Strategic%20Asset%20Managment%20at%20the%20Port%20of%20Melbourne.pdf

M Buglar, S. &. (1994). 4.0 Design of Marina Structures and Facilities. In S. &. M Buglar, *Environmental guidelines for marinas in the Great Barrier Reef Marine Park* (p. 102). Cairns: Great Barrier Reef Marine Park Authority. Retrieved from http://www.pontiligalleggianti.it/dati/ContentManager/files/Downloads/marina%20design%20guidelines.pdf

M. A. Marutla, K. M. (2010). *Infrastructure Engineering: Manual for Track Maintenance.* Johanessburg: Transnet Freight Rail.

MAG, T. S. (2015). *Port of Ngqura and Port of Port Elizabeth Evolutions at South Africa's ports*. Retrieved July 18, 2018, from https://thesa-mag.com/features/transport/port-of-ngqura-and-port-of-port-elizabeth-evolutions-at-south-africas-ports/

Management, G. F. (2014, March). *The Asset Management Landscape Second Edition.* Retrieved January 18, 2019, from http://www.gfmam.org

Marine_Education_Ebook_Series/. (n.d.). *South Africa's Ocean currents.* Retrieved from Oceans Aware: http://cdn2.hubspot.net/hub/288079/file-788564994-pdf

Marius Rossouw, J. S. (2011). Real Time Observations and Forecasts in the South African Coastal Ocean . *CSIR*.

McCleland, D. (2016, May 17). *The Three Eras of the Historic Port Elizabeth Harbour.* Retrieved Aug 10, 2018, from http://thecasualobserver.co.za/the-three-eras-of-the-historic-port-elizabeth-harbour/

McCleland, D. (2017, April 15). *Port Elizabeth of Yore: Early Days of the Harbour and Shipping.* Retrieved August 10, 2018, from http://thecasualobserver.co.za/port-elizabeth-yore-early-days-harbour-shipping/

McKenna, A. (2009, February 11). *Durban History - Port Natal.* Retrieved from Encyclopaedia Britannica: https://www.britannica.com/place/Durban#accordion-article-history

MG Stewart, X. W. (2010). *Climate Change Impact and Risks of Concrete Infrastructure Deterioration.* Melbourne: Commonwealth Scientific and Industrial Research Organisation (CSIRO).

MG. Stewart, X. W. (2010, March 25). *Climate Change Impact and Risks of Concrete Infrastructure Deterioration.* Retrieved from Science Direct: https://www.sciencedirect.com/science/article/pii/s0141029611000241

Mitchell, M. (2014, March 01). Chapter 2: Early days of railways and harbours. *SAICE: Civil Engineering: A brief history of transport infrastructure in South Africa up to the end of the 20th century*, pp. 74-77.

Mneney, T., Modipane, K., Nxumalo, H., & Bilse, D. (2015). *Engineering: Asset Maintenance Principles and Procedures.* Johannesburg: Transnet National Ports Authority - Standard Operating Procedures.

Moore, R. (2014). *Asset Management? Or, Maintenance Management, Rebranded?* Retrieved February 06, 2017, from https://reliabilityweb.com/articles/entry/asset_management_or_maintenance_management_rebranded/

Moubray, J. (1997). Proactive Maintenance. In J. Moubray (Ed.), *Reliability Centered Maintenance* (pp. 128 - 155). Oxford: Butterworth - Heinemann.

Municipalities, F. o. (2018, June 14). *Asset Management for Municipal Staff: The Technical Basics Participant Workbook.* Retrieved September 23, 2018, from https://rmalberta.com/wp-content/uploads/2018/07/participant_workbook_final_june_14_2018_reduced-SMALL.pdf

Municipality, S. P. (2015, May 27). *Asset Management Policy.* Retrieved November 22, 2018, from http://www.solplaatje.org.za/CityManagement/Policies/Documents/SPM%20Asset%20Management%20Policy_2015.pdf

Municipality, S. P. (2015, May 27). *Sol Plaatje Local Municipality - Asset Management Policy.* Retrieved December 02, 2018, from http://www.solplaatje.org.za/CityManagement/Policies/Documents/SPM%20Asset%20Management%20Policy_2015.pdf

NAMS. (2014). *Supplement to the IIMM 2011: Quick Guide to Meeting ISO 55001 Requirements.* New Zealand: New Zealand National Asset Management Support Group (NAMS) and the Institute of Public Works.

National Government of South Africa. (2018, October 02). *Ports Regulator of South Africa.* Retrieved from National Government of South Africa: https://nationalgovernment.co.za/units/view/268/ports-regulator-of-south-africa

North West Provincial Government. (2004, April 04). *Asset Management Framework Version 3.3.* Retrieved from North West Provincial Government: https://www.nwpg.gov.za/Human Settlements/site/documents/policies/Asset%20Management%20Framework%20v3.3%202004.pdf

North West Provincial Government. (2019, April 04). *North West Provincial Government.* Retrieved from http://www.nwpg.gov.za/HumanSettlements/site/documents/policies/Asset%20Management%20Framework%20v3.3%202004.pdf

O'Hanlon, T. (2014). *Research Report on Asset Management Practices, Investments and Challenges 2014 - 2019.* Florida: Reliabilityweb.com, Uptime Magazine.

Osborne, P. (2017). *What else affects temperature (AND rainfall)?* Retrieved August 09, 2018, from https://slideplayer.com/slide/10561983/

Paul E Haglar Jr, J. T. (2012, October). *Asset Management vs Maintenance Management.* Retrieved from Leavitt Communications: http://leavcom.com/2012f/la_100012.php

Philip, L. (2015). Archaeological Impact Assessment (AIA) - (Part 2 of HIA) - For the Proposed Rehabilitation and Refurbishment of the existing Latimer's Landing jetty. *Transnet Capital Projects, 1*, 73.

PIANC. (2008). *Life Cycle Management of Port Structures Recommended Practice for Implementation.* Brussels: PIANC - The World Association for Waterborne Transport Infrastructures.

PIANC. (2017). Health Monitoring for Port and Waterway Structures. *PIANC - The World Association for Waterborne Transport Infrastructure, 6*(199), 3.

Plessis, D. B. (1976). *History and development of the Port of Mossel Bay.* Johannesburg: THE CIVIL ENGINEER in South Africa.

Plessis, G. d. (2010, March 16). Construction of the Port of Ngqura. *Transnet National Ports Authority*, pp. 1-41.

Plessis, G. d. (2010, August 01). *SAICE - Civil Engineering.* Retrieved July 09, 2018, from Construction of the Port of Ngqura - Phase 2: Maritime and Civil Works,November 2006 to May 2011: https://www.civildesigner.com/press/ngqura_aug1.pdf

Port of Melbourne. (2019, March). Retrieved from Port of Melbourne's Integrated Management System: https://www.portofmelbourne.com/about-us/about-the-port/integrated-management-system/

Port of Rotterdam. (n.d.). *Strategic-location.jpg / Port of Rotterdam*. Retrieved from Port of Rotterdam: https://www.portofrotterdam.com/en/files/strategic-locationjpg

Ports & Ships, S. &. (2011, January 19). *Port of East London*. Retrieved July 10, 2018, from Ports & Ships - shipping and harbour news out of Africa: http://ports.co.za/east-london.php

Ports & Ships, S. (2015). *Port of Ngqura*. Retrieved July 13, 2018, from http://ports.co.za/coega.php

Ports & Ships, S. (2017, October 28). *The Port of Richards Bay*. Retrieved September 06, 2018, from Ports and Ships - shipping and harbour news out of Africa: https://ports.co.za/richards-bay.php

Ports & Ships, S. o. (2017, November 13). *Port of Port Elizabeth*. Retrieved August 10, 2015, from Port & Ships - shipping and harbour news out of Africa: https://ports.co.za/port-elizabeth.php

PRDW, C. P. (2015). Transnet National Ports Authority, Port Engineering Handbook. In *TNPA, Port Engineering Handbook* (p. 438). Johannesburg: PRDW.

Primmer, M. (2019, August 5). *AMCI 2020.* Retrieved from Condition monitoring, the 80/20 rule, and advice for asset managers: https://assetmanagementevent.com.au/condition-monitoring-the-80-20-rule-and-advice-for-asset-managers/

RIVER, C. O. (2013). *City of Powell River - Marine Asset Management Plan.* POWELL RIVER.

Roelse, F. (2014). *Stability of slope material affected by bow thrusters at open quay structures.* Delft: Delft University of Technology.

Rowan, A. G. (2007). *Repair and Rehabilitation of Reinforced Concrete Harbour Structures.* Retrieved from University of Cape Town.

Russell, K. S. (1982). *Coastal Engineering in South Africa.* Stellenbosch: National Research Institute for Oceanology, Stellenbosch.

S. Dupray, J. K. (2010). The use of concrete in maritime engineering – a guide to good practice. *CIRIA*(C674), 44.

SAICE. (2017, September 28). *SAICE Infrastructure Report Card 2017.* Retrieved from South African Institute of Civil Engineering (SAICE): https://saice.org.za/saice-infrastructure-report-card-2017-2/

Salim Amod, K. W. (2012, May 1). SAICE's report cards on the state of infrastructure. *ICE - Institute of Civil Engineering - Management, Procurement and Law Volume 165 Issue MP2*, pp. 119-127.

SAS Brown, C. E. (1994). Port Engineering Handbook. *Portnet, 2*(2), 97.

Sciortino, J. (2010). Fishing harbour planning construction and management. Rome: FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.

Sciortino, J. (2010). *Fishing harbour planning,construction and management - Quays & Slipways.* Rome: Food and Agriculture Organisation (FAO) of the United Nations .

Secretariet, H. O.-O. (2017). *Oceans Economy Summary Report.* Johannesburg: Operation Phakisa - Republic of South Africa.

Shepherd, J. (2015, November 19). *City of Bunbury Asset Management Plan 2015/16 – 2023/24.* Retrieved December 01, 2018, from http://www.bunbury.wa.gov.au/pdf/Council/Asset%20Management%20Plan.pdf

SIMCO, I. (2020). Retrieved from PORT OF ROTTERDAM – KMS SYSTEM: https://www.simcotechnologies.com/projects-and-references/port-of-rotterdam-kms-system/

Smith, P. (2016). Notable Southern African marine structures. In P. Smith, *Types of Marine Concrete Structures.* Woodhead publishing.

South African History, o. (2011, March 16). *East London.* Retrieved July 09, 2018, from South African History Onine towards a peoples history: https://www.sahistory.org.za/places/east-london

Specialty, A. G. (2016). *ARC Marine – Marine Port Structure Guidance*. Retrieved August 31, 2017

Strategies(TIPS), T. a. (2014). *Review of regulation in the Ports Sector.* Johannesburg: University of Johannesburg.

Straton, A. (2015, March 13). *How the Dom Pedro Jetty was named*. Retrieved from My PE News: http://mype.co.za/new/how-the-dom-pedro-jetty-was-named/47121/2015/03

Strohmeier, J. H. (1994). Deterioration of reinforced concrete in a marine evironment: repair costs and maintenance strategies. Cape Town: University of Cape Town.

Stuff, S. F. (n.d.). *Major Ocean Currents.* Retrieved SEPTEMBER 06, 2018, from http://app01.saeon.ac.za/sadcofunstuff/MajorOceanCurrents.htm

Sullivan, E., & Rykers, G. (2010, December 17). *Port of Melbourne.* Retrieved from Condition Manual:

file:///C:/Users/0133199/Desktop/Port%20of%20Melbourne%20Condition%20Manual.pdf

Surbhi, S. (2017). *Difference between Port and Harbour*. Retrieved September 4, 2018, from https://keydifferences.com/difference-between-port-and-harbour.html

T Mneney, K. M. (2015). *Engineering: Asset Maintenance Principles and Procedures.* Johannesburg: Transnet National Ports Authority - Standard Operating Procedures.

Technologies, P. &.-S. (n.d.). *PORTS & MARITIME - AGING AND DETERIORATING STRUCTURES – WHAT TO DO TO PRESERVE OUR INFRASTRUCTURE* . Retrieved August 15, 2018, from https://www.simcotechnologies.com/our-markets/ports-maritime/

The Natal and Zululand Annual, A. J. (1926). *The Story of Port Natal*. Retrieved August 31, 2018, from https://www.fad.co.za/Resources/dhew/story/pn.htm

Theofanis Sotirios, M. B. (2007). Port Asset Management: The Role of Port Auhtorities and Marine Terminal Operators –A Systematic Approach. New Orleans: RUTGERS, The State University of New Jersey.

Thoresen, C. A. (2014). *Port Designer's Handbook* (3rd ed.). (T. T. Ltd, Ed.) London: Institute of Civil Engineers.

Tisheh, I. (2015, March 19). *Delft University of Technology.* Retrieved September 15, 2018, from https://repository.tudelft.nl/islandora/object/uuid%3A574c23d1-be05-408c-8069-e5de3330f7a2

TNPA. (2018, September 18). *Position paper on Transnet National Ports Authority.* Retrieved from Ports Regulator of South Africa: https://www.portsregulator.org./images/documents/position_paper_on_Transnet_National_Ports_Authority_18_Sep.pdf

TNPA Infrastructure, P. D. (2017). *TNPA National Port Plans.* Durban: TNPA.

TNPA Ports & Ships, S. (2017, November 12). *Port of Saldanha Bay*. Retrieved September 07, 2018, from Ports & Ships - shipping and harbour news out of Africa: http://ports.co.za/saldanha-bay.php

TNPA, C. E. (2010). *Asset Maintenance Principles and Procedures - Part 1 : Principles.* Johannesburg: Transnet National Ports Authority.

Transnet National Ports Authority. (2018). *Transnet National Ports Authority.* Retrieved from Transnet: https://www.transnet.net/InvestorRelations/AR2018/TNPA.pdf

Transnet SOC. (2017). *Chapter 4 - Port Development Plan - Long Term Planning Framework.* Retrieved from Transnet SOC: https://www.transnet.net/BusinessWithUs/LTPF%202018/4.%20LTPF%202017_Port.pdf

Tsang, E. (2012, January 03). *Asset management — Overview, principles and terminology.* Retrieved from ISO/CD 55000.2: http://sajie.journals.ac.za/pub/article/downloadSuppFile/576/34

Tsang, E. (2012, February 26). *ISO/CD 55000.2 Asset management — Overview, principles and terminology.* Retrieved October 09, 2018, from sajie.journals.ac.za/pub/article/downloadSuppFile/576/34

Veracity Asset Management Group. (2015, January 28). *ISO 55000 Meet Youe (New Friend) Sam.* Retrieved from Veracity Asset Management Group: Wordpress.com: https://veracityamg.wordpress.com/2015/01/28/iso-55000-meet-your-new-friend-sam/.

Vollgraaff, J. (2016, March 15). *The Historical Mossel Bay Harbour*. Retrieved from Diaz Beach Haven Rentals : http://www.diazbeachhaven.co.za/the-historical-mossel-bay-harbour/

Voogt, H. (2013, November 08). *Port of Rotterdam.* Retrieved from Asset Management - Quay Walls: https://aapa.files.cms-plus.com/SeminarPresentations/2013Seminars/13FacEng/Voogth_Henk.pdf

Voogt, H. (2017). Port of Rotterdam's Road to World-Class Asset Manangement. *Last Longer Middle East Conference* (p. 38). Dubai: Port of Rotterdam.

W vd Molen, H. (2009). General Characteristics of South African Ports and the Safe Mooring of Ships. *28th South African Transport Conference (SATC 2009)* (p. 7). Pretoria: CSIR Built Environment.

Wikipedia. (2018, April 10). *Port of Cape Town*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Port_of_Cape_Town

Wikipedia. (n.d.). *Mosselbay - Wikipedia*. Retrieved September 7, 2018, from https://en.wikipedia.org/wiki/Mossel_Bay

Wikipedia. (n.d.). *Port of Cape Town - Wikipedia*. Retrieved September 7, 2018, from https://en.wikipedia.org/wiki/Port_of_Cape_Town

Wikipedia. (n.d.). *Richards Bay - Wikipedia*. Retrieved September 6, 2018, from https://en.wikipedia.org/wiki/Richards_Bay

Wikipedia. (n.d.). *Saldanha Bay - Wikipedia*. Retrieved September 7, 2018, from https://en.wikipedia.org/wiki/Saldanha_Bay

Wikipedia, t. f. (n.d.). *Berth (moorings)*. Retrieved September 10, 2018, from https://en.wikipedia.org/wiki/Berth_(moorings)

Williams, R. M. (2012). Ten Major Elements of Asset Management System.

Williamson, R. M. (2012). *Asset Management vs. Maintenance Management.* New York City: Strategic Work Systems, Inc.

Williamson, R. M. (2012). Asset Management vs. Maintenance Management. Columbus: Strategic Work Systems, Inc.

Wire, R. H. (2007, January). *The RCM Perspective on Maintenance.* Retrieved from Reliability Hot Wire - The eMagazine for the Reliability Professional: https://www.weibull.com/hotwire/issue71/hottopics71.htm

APPENDIX 1 – PFMA ASSET MANAGEMENT

10

Asset management

10.1 Responsibility for asset management [Section 38(1)(d) of the PFMA]

10.1.1 The accounting officer of an institution must take full responsibility and ensure that proper control systems exist for assets and that–

(a) preventative mechanisms are in place to eliminate theft, losses, wastage and misuse; and

(b) stock levels are at an optimum and economical level.

10.1.2 The accounting officer must ensure that processes (whether manual or electronic) and procedures are in place for the effective, efficient, economical and transparent use of the institution's assets.

10.2 Disposal and letting of assets [Section 76(1)(k) of the PFMA]

10.2.1 Disposal of movable assets must be at **[book]** market value or by tender or auction, whichever is most advantageous to the state, unless determined otherwise by the relevant treasury.

10.2.2 Any sale of immovable state property must be at market value, unless the relevant treasury approves otherwise.

10.2.3 The letting of immovable state property (excluding state housing for officials) must be at market-related tariffs, unless the relevant treasury approves otherwise. No state property may be let free of charge without the prior approval of the relevant treasury.

10.2.4 The accounting officer must review, at least annually when finalising the budget, all fees, charges, rates, tariffs or scales of fees or other charges relating to the letting of state property to ensure sound financial planning and management.

10.3 Assets accruing to the state by operation of any law [Section 76(2)(i) of the PFMA]

10.3.1 Where any money, property or right accrues to the state by operation of law *(bona vacantia)*, the responsible executive authority may exercise all powers, authority and prerogatives, and fulfil any obligation on behalf of the state.

ANNEXURE 1 – ASSET CONDITION INSPECTION SHEET