Decision Support for Port Investments under Uncertainty: A Real Options Approach

by

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The conceptualisation of this research was a true product of random events that connects the dots as I look at it backwards. It might be the humorous yet very militant writing style of Nassim Nicholas Taleb that made me curious about uncertainty in decision making. It was the combination of classes in financial engineering and infrastructure asset management, which made me enthusiastic about the financial implications of decision making for infrastructural management. It was a combination of my coursework, Tim Harford's podcast and books on randomness which sowed the seeds for this research.

Through some words, I would like to take the time and space to express, my deepest gratitude to all those individuals who have helped me in this endeavour. It is my university and company supervisors who allowed me to sharpen this research. While my friends and family made the supporting cast to ensure my well being.

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To further research endeavours in decision making and optimisation

Adithya Eswaran
Delft, 2021

Executive Summary

Introduction

Large infrastructural projects involve large upfront capital outlays which are irreversible once the decision on the asset is made. The decision to either or expand an infrastructure is made with a certain expectation of key parameters of the future. For port infrastructural decision making, the decision-maker intends to bridge the gap between “What the port is doing” and “What the port should be doing”. In most cases, the decision-maker develops or expands the port on an expectation of future traffic which can be handled by the port. The future throughput volumes play a significant role in determining the financial viability of the project. The decision on the port infrastructure is more often based on the financial viability which is obtained from a financial model. A traditional static Discounted Cash Flow (DCF) approach models on the implicit assumption of “Now or Never” decision-making strategies.

However, the decisions on the port infrastructure have been seen to be riled with uncertainties stemming from the market, price, technology, institutional, political and competitive landscape. The effect of these uncertainties influences the financial success of the project. Within academic literature, it is the uncertainty in demand which has been observed to be a major source of uncertainty that is considered in a numerical model for Real Options Analysis (ROA). The addition of scenario analysis, sensitivity analysis, Monte-Carlo simulations and expert judgement is observed to be the current strategies for the consideration of the effect of the uncertainty sources. However, these additions to the standard DCF model are limited in terms of the number of paths t be considered and builds on deterministic strategies of development or expansion. These methodologies present the predict and control approach to the decision-making process.

Real Options Analysis is said to give the decision-maker the right but not the obligation to exercise an investment decision. Applications of ROA in variety of field suggests that it is an alternative approach to predict and control wherein the decision-maker is considered to be an active manager who adapts the decisions based on the real-time developments. This approach presents an alternative consideration to valuation wherein the underlying parameter of uncertainty is connected to the valuation model. This dynamic evaluation allows the decision-maker to exercise an investment based on the movement of uncertainty parameter and exercise at the time of maximum pay-offs. Options are most likely to be embedded in the project which can be evaluated for their pay-off potential based on a range of movements of the uncertainty in the considered timeline.

Agenda of Research

Expansions for future demand? How much capacity will be required? Until when the decision can be postponed? When to expand? What should be the magnitude of expansion? What is the position of such an investment? These are some of the questions which the port authorities are subjected to in case of an expansion decision. Through the implementation of ROA on a real-time case study, insights on these questions are obtained.

However, to develop these insights using the ROA, there is a requirement to understand the process mechanics of ROA in depth. Although ROA has significant consensus in terms of its potential and theoretical framework. The variety in the methodologies makes these frameworks rather confusing. Moreover, these methods involve opaque assumptions in terms of the use of discount rates, usage of probabilities and arbitrage assumptions. Additionally, there is an observed lack of clarity in applying ROA to port specific cases in terms of process mechanics. The influence of ROA on the underlying business case for the port authority is also limited. Finally, the momentum around ROA in literature gives an opinion that ROA is the answer to the value of flexibility.

This thesis focuses on building a sufficient understanding of the current methods for ROA applications for infrastructural and more specifically port infrastructures. This understanding will shed light on the methodological gap and further allow for the design of a conceptual framework which is then tested by devising a numerical model. Designing the numerical model will allow for the evaluation of the potential of ROA within port infrastructures. finally, the comparative analysis between a ROA and a standard DCF allows adding to the current knowledge pool.

Addressing these gaps, through the following Main RQ, this research is positioned to investigate the value-added through ROA over the existing valuation and decision-making protocol. The Main-RQ which is investigated through this research is:

Main RQ: ***What is the potential value of implementing Real Options Analysis within port infrastructural decision making?***

Methodology

To answer the research question an innovation funnel methodology is used wherein the elements of both design and evaluation methods of research are incorporated. Starting with the phase of exploration, the current works on real options analysis is studied which allows for developing an understanding of the baseline approaches and the implementation approaches within infrastructural systems. Secondly, exploratory interviews are conducted with experts from Royal HaskoningDHV. Based on the perspectives of the experts the sources of uncertainty in port infrastructural investments is extracted. Additionally, these perspectives are noted while further designing the conceptual framework and further used during the discussion of the model results. Finally, in the exploration phase, the current case study is introduced, analysed and discussed.

Based on the results of the desk research and exploratory interviews a conceptual framework for real options analysis is devised. This framework was contextualised to the complexities of brownfield port expansions. Further, the conceptual framework has been devised for transparency, comprehensibility and practical relevance. Based on this conceptual framework an operational numerical model derived for the case of African Port. The application of the numerical model is expected to provide the decision-maker with optimal moments and magnitude of the expansion. The results and the analysis of the numerical model can be expected to provide insights into the effects of delaying and phasing. These results are then evaluated against the baseline values derived from the static DCF model.

Conceptual framework

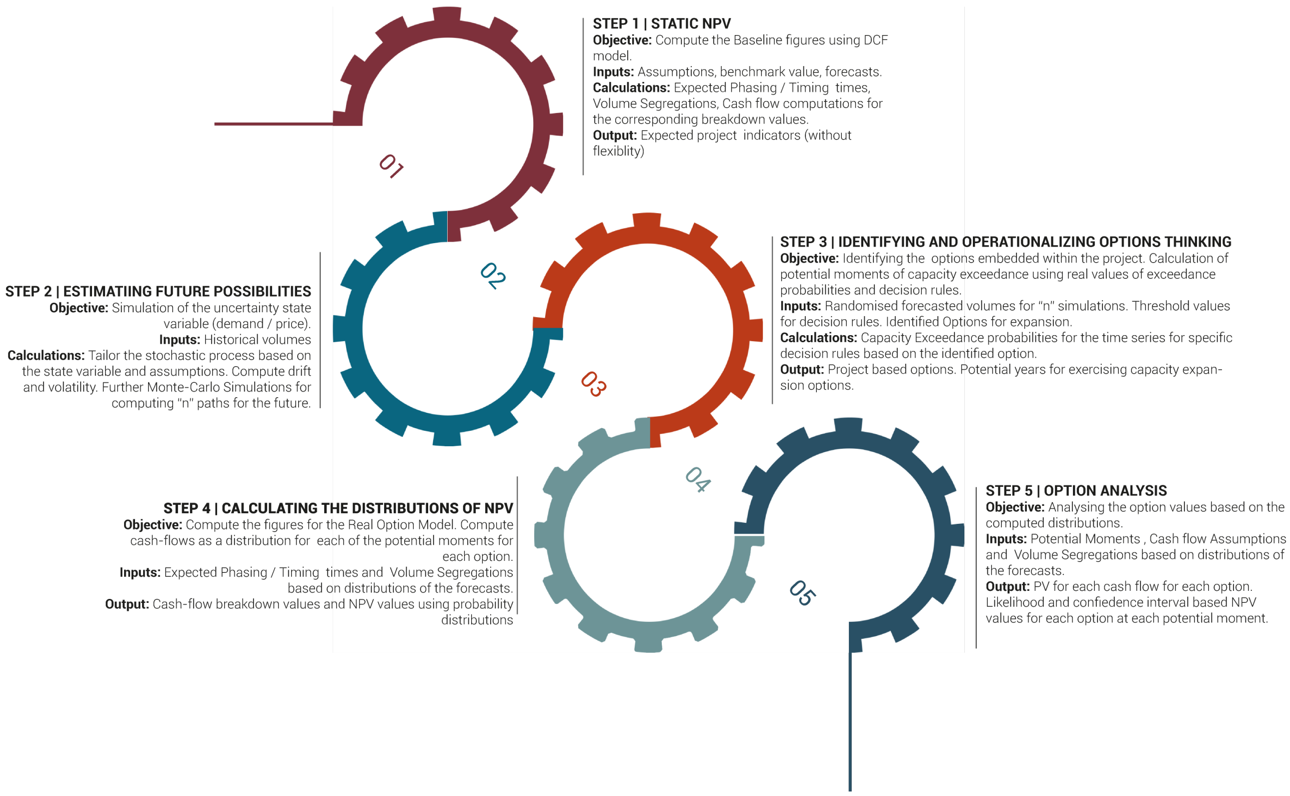

Figure 1: Overall Steps for the Conceptual Framework

One of the significant critiques of real options analysis has been its limited practical relevance due to the use of complex mathematics and lack of transparency. There is limited mention of the underlying assumptions for the stochastic process, discount rates and process mechanics. The proposed conceptual framework can be executed in five distinct steps. The methodologies involved in the conceptual framework is grounded in previous applications of ROA in infrastructural decision making. Moreover, the conceptual framework ensures the use of a practitioner's tool in terms of Microsoft Excel, Monte-Carlo Simulations and Sensitivity Analysis. The conceptual framework reasons the assumptions used employed for the calculation of values. The overall steps for the conceptual framework have been visualised in Figure 1. The proposed conceptual framework ensures practical relevance, comprehensibility and transparency of reasoning/assumptions.

To derive a numerical model from the conceptual framework there is a requirement of baseline static DCF model, project indicators, historical throughput volumes and assumptions for the underlying cash-flows. The conceptual framework is devised for applying ROA in brownfield expansion investments.

Results of the numerical model

A total of 10 embedded options were extracted from the current static expansion strategy for the case of African Port. A total of 100 strategies were derived as an output of the decision rules. There was a total resultant of 100 distribution of Net Present Value (NPV) values from step-4 of the conceptual framework. The current static DCF model evaluates a single strategy of expansion wherein the total magnitude of expansion of 1050,000 TEU takes place at once. The current numerical model as mentioned evaluates numerous growth pathways. The static DCF model for the case does not analyse for optimal moment and magnitude of the expansion. On the other hand, the numerical model analysed for the optimal moment and magnitude of the expansion. Based on the analyses on potential moments and magnitudes of expansion and value of flexibility and optimal adaptation for the expansion plan for the African Port has been derived. The optimal strategy of adaptation is shown by the expansion option wherein the total magnitude of expansion is 525,000 TEU (first moment of expansion = 2020 | second moment of expansion = 2027 | first-moment magnitude of expansion = 225,000 TEU | second-moment magnitude of expansion = 300,000 TEU). The reason for this option being the optimal expansion adaptation stems from its highest expected NPV value in comparison to other values. Additionally, this option has a value of flexibility greater than 0. Finally, this option also sits on the higher range of the calculated probabilities of net payoffs exceeding the initial capital outlay.

The expected NPV for the proposed adapted strategy amount to 9.112 Million EUR. To compare, the current outcomes of the static, and expected for NPV was calculated. The comparison of these expected NPV values shows that the port authority can save 17.063 Million EUR by adopting the proposed expansion strategy. The current expansion plan of installing 1050,000 TEU does not pose a benefit in terms of the project outcome. To further verify the value of the numerical model, the adapted strategy was compared against a test case wherein the expected NPV for an inflexible strategy of the magnitude of expansion 525,000 TEU was tested. The comparison of the inflexible strategy against the flexible strategy for a similar magnitude suggests, the port authorities can still save 0.745 Million EUR.

Apart from the monetary benefit of the flexible strategies, it allows for the decision-maker to postpone their investments and also alter the scale of investments. Subject to the validity of all the cash-flow assumptions, it can be observed that the current expansion strategy will result in excess capacity for which the government is spending a huge upfront Capital Expenditures (CAPEX) of 350 Million EUR. Adaptation through the proposed optimal strategy can allow for breaking down the CAPEX into smaller parts and allow for a more dynamic decision-making scenario. Other sets of static options which are optimised for operations indicate a higher expected NPV values than all of the flexible strategies. For an expansion case of 750,000 TEU, the comparison of option by higher operational utilization against current levels of operational utilization allows for saving 4.12 Million EUR. Therefore, the results indicate that the decision-maker can gain more from optimising the operations.

Conclusion

Firstly, ROA should not be mistaken for a forecasting methodology. Rather ROA allows for calculating and analysing multiple pathways through which an expansion plan can be adapted. Through limited validation interviews, a similar observation was made, wherein ROA allows for identifying the growth paths.

ROA implementation can be said to be useful in the pre-feasibility stages, wherein the possibilities for multiple timing and magnitudes can b checked. The sophistication of the assumptions can be scaled based on the data. But using ROA on a later stage will require a fundamental change to the way the financial model is built, which might make it time-consuming and occupationally intensive. In the later stages, the use of evaluation indicators also change. There is a shift from NPV to more sophisticated financial indicators. ROA does not inform on those indicators, making it limited in terms of its use for final investment decision stages.

ROA allows for the consideration of managerial flexibility and active management. It can allow developing strategic foresight from the point of view of the decision-maker. According to the experts in the validation interviews, ROA can be used as decision support rather than a full-fledged valuation tool. Unlike static DCF approaches ROA does not follow: “predict and control strategies” and planning for excess capacity. As the focus is maintained on flexibility the “Now or Never” notion of the inflexible strategies valued through static DCF can be bypassed.

However, Real Options (RO) can prove to be of little value in cases wherein there is no historical data available on the underlying uncertainty variable. ROA can be used for opportunistic use. There can be other opportunistic agendas (political or strategic) in the case of decision-makers involved with real assets.

The essence of ROA diminishes as soon as the evaluation is done based on the polarity of Mean NPV value. At the crux of ROA is to use the resultant distribution of NPV to identify for likelihoods, probability of occurrence and expectation values. Through ROA the decision-maker can learn more about their position on the investment. ROA is a way of assessing alternative strategies which can be adapted based on the consideration of multiple scenarios (which are influenced by the uncertainty parameter) that are affected by shocks to result in a distribution of outcomes that can allow for probabilistic analysis. To put it simply, this is a combination of scenario analysis, Monte-Carlo simulations and probabilistic analysis over a static DCF model. Therefore, ROA presents the value of being an additional calculation over static DCF in a more holistic manner.

Limitations

The main limitations of this research stem from its applicability, nature of flexibility and the indicative nature of results. Firstly, the current wealth of literature on real options analysis for greenfield projects are limited. Additionally, there is a deeper requirement to analyse the market conditions to specify the future trends for the greenfield ports. This additional complexity has not been considered in the design of the conceptual framework. Secondly, the research focuses on flexibility “on” systems instead of flexibility “in” systems. Flexibility “in” systems involves the development of flexibility in the design of the port. Such a focus requires a deeper grasp on the design specifications of the port, which was not considered to be the main focus of this research. Finally, the results of the numerical model are deeply influenced by the assumptions. This is also one of the limitations of real options analysis, wherein the focus is maintained on the methodology and the value of having options. This research too lacks in validating the baseline assumptions for the cash-flows. Variance in these assumptions can affect the total project value. Thereby, influencing the effectiveness of the optimal route of expansion.

Recommendations

The devised conceptual framework and the numerical model does not conform to the notion of “one strategy fits all application”. The framework and the numerical model comes with a set of disclaimers and can be only applied correctly to a subset of port expansions. To make it efficient for more applications, the numerical model is required to be applied in iterative stages and is to be modified with the patterns of the uncertainty parameter.

Firstly, it is not recommended that a real options numerical model is applied for “accurately valuing” the project expansions. The forceful application can lead to loose assumptions and lead to an erroneous value. Secondly, real options analysis should not be viewed as a holy grail of valuation methodology which can allow for deriving the optimal strategy which can maximise the pay-offs. The numerical model from real options analysis reflects the baseline assumptions of the static discounted cash flow model. Hence, it does not magically maximise the total project value. Rather it provides the decision-maker with a set of alternative options which can be used based on the behaviour of the uncertainty parameter. Thirdly, real options analysis is not a stand-alone model, it is derived from a static discounted cash flow model. Therefore, there is a requirement to validate the assumptions used in the static discounted cash flow model. Similar to scenario or sensitivity analysis, real options analysis is an add-on to the static DCF model. However, unlike scenario and sensitivity analysis, real options analysis allows the decision-maker to break the project into options and calculate for its efficiency against the movement of the chosen uncertainty parameter. The key to using real options analysis is to involve the design and financial modelling team together. Doing so will allow to identify flexibility both “on” and “in” the project. Moreover, the client should be also engaged in the process by educating them on the advantages of real options analysis over the traditional valuing techniques. This will ensure co-creation in the process and enrich the efficacy of the identified options. Finally, the organisation can implement real options analysis in stages through decision trees extending up to a complete numerical model as shown in this research. The consultants can record their learning from projects and can reflect on the same using options thinking approach. Smaller use cases can also be developed for the application of ROA and initiate the iterative cycle for the development. Applying it in stages will allow for recording the results and improve the comprehensibility and the transparency of real options analysis. This will increase its practical acceptance.

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Acronyms

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Defining the Context

A surprising number of government committees will make important decisions on fundamental matters with less attention than each individual would give to buying a suit.
-Herman Kahn

A succinct discussion of the field, need and agenda of research is presented in this chapter. The chapter builds further into the detailed problem analysis, research context and the outlined scope. Finally, it concisely mentions the organization of the contents mentioned within this document.

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1. Defining the context

Introduction | Problem Definition | Why ROA for Ports and Infrastructures?

Agenda of Research | Scope and Relevant Outcomes

1.1. Introduction

Globally we are said to live in cycles of development, where technological innovations are seen to continually displace existing technologies (de Neufville and Schotles,2011). Post the industrial revolution, universally, technological systems have gained the reputation of growing rapidly. This rapid growth rate allows for innovations while making the existing technologies obsolete. For instance, cellular mobiles were first introduced in the marketplace as a model for communication. Over time, it has developed into a piece of entertainment that is physically confined to the palm but its reach is far more than it can be fathomed. Cellular mobile phones of the 1990s and the 2000s are now obsolete. These rapid changes create uncertainty for the future. One cannot accurately predict the shape or the form of a particular industry. On a broader look, the uncertainty within a particular industry can arise but not limited to the behaviour of stakeholders, consumer patterns, demand growth, government mandates etc. Uncertainties within the future are said to consist of opportunities and threats. Chief Financial Officers are always wary of these uncertainties while pursuing the future growth interests of the organization (Myers and Brealey,1995). Within the practice of corporate finance, the risk within an investment is measured by the spread of the returns through the standard deviation. The risk held within this spread is managed and reduced through diversification strategies which are not limited to the Capital Asset Pricing Model, Arbitrage Pricing Theory and Adjustment of discount rates. Organizations seeking growth opportunities employ sensitivity analysis, break-even analysis and scenario analysis for understanding the uncertainties which might affect their project-related ambitions (Myers and Brealey,1995). The influence of uncertainties and risks dominate the discourse on investment decisions.

Myers (1977), offered a perspective to exploit the upside of the risk and identify the value of the opportunities held within the uncertainty. The proposition builds further on the financial options pricing method by Black and Scholes (1973).Since then, the options pricing method for real-time assets have gained relevance as RO and has become a research niche. Specifically, this kind of valuation has found a place in capital investment dominated industries, such as oil and gas. For instance, the whole oil extraction process is broken down into various stages and the decision to move ahead with the next stage depends upon the results of the previous stage (Leslie and Michaels,1997).

Infrastructural systems are said to be long-term projects involving large investment costs existing within the context of high uncertainty arising from demand or price uncertainty (Cruz and Marques,2013). The concept of RO as coined by Myers (1977) was further implemented by researchers within infrastructural systems. It was recognized that the fluctuations stemming from the markets and behaviour of institutions have deep impacts on the financial viability of projects. These impacts on the financial viability of the planned infrastructure are have been recorded for infrastructural projects (Martins et al.,2013). De Neufville (1991), suggested that incorporation of flexibility within the decision stage allow for the infrastructural system to be adapted to a certain change in the future. de Neufville et al. (2005) also showed that flexibility has value once it is plugged into the traditional DCF valuation model.

Copeland and Antikarov(2001) claims that the practitioner or the manager can exercise strategic management of the project or product development cycles through the application of ROA. ROA has been touted as a better alternative to a DCF financial model. This due to the DCF methodology employs a deterministic methodology leading to a single stream of cash-flows (Guthrie,2009b). Such a single stream of cash flow does not capture the underlying variations within the DCF valuation model. Although the existing DCF models can be adjusted for risk and uncertainty consideration, the DCF models fail to capture the options thinking approach and mechanics as proposed by ROA. The DCF models consider cash-flows as single streams of inflow/outflow making it incompetent to capture the dynamic nature of the variables involved within the valuation model (Taneja et al.,2010). A stand-alone DCF model without elements of stochasticity can be said to offer limited flexibility for implementing strategic decisions. Within the next section section 1.2, the issues with a deterministic valuation model (of the likes of stand-alone DCF models) will be closely discussed under the context of port infrastructural decision making.

Although ROA has significant momentum as a valuation methodology, the variations in approaches and assumptions have been observed to be confusing. According to Borison(2003), the vague specification of requirements and process mechanics, coupled with computational complexity and specific jargons, are said to some of the factors which restrict the use of widespread use of ROA.

1.2. Problem Definition

Throughout the world governments have been involved in uncertain decision-making environment involving large complex infrastructural systems which are intended to maximise economic activity and result in the development for the region (Bielenberg et al.,2020)(Van Rhee et al.,2008). Bielenberg et al.(2020), claims that there is worldwide spending of greater than 2.5 trillion dollars a year on infrastructural systems and networks. Another report by Jonathan Woetzel and Palter (2017) suggests, there is a global spending requirement of 3.7 trillion dollars per year to ensure that, the infrastructural systems and networks will keep pace with the projected Gross Domestic Product (GDP) growth through 2035 (Jonathan Woetzel and Palter,2017).

Considering that infrastructural investments form such a huge chunk of the GDP it is vital that, the governments and private actors alike, throughout the world, finance their capital and operating expenditures in a sustainable manner. Such an item of expenditure is expected to yield the anticipated social and economic advantages (Jonathan Woetzel and Palter,2017). However, reality shows otherwise, it is observed that many projects become an economical and financial burden for the government (Jonathan Woetzel and Palter,2017)(Bielenberg et al.,2020) (Flyvbjerg et al., 2003). Governments have been observed favouring certain investments for strategic and political reasons by focusing on the benefits and neglect the uncertainties (Van Rhee et al.,2008).

1.2.1. Need for Research

The decision-making process for infrastructural systems involve parameters such as NPV, Internal Rate of Return (IRR) and Payback Period which are obtained from a DCF analysis (Geltner and De Neufville, 2018) (de Neufville and Schotles,2011) (de Neufville et al.,2005). The use of these project parameters aid in understanding the feasibility of the project and analyse the associated risks. A DCF model operates on a single stream of cash flow making it seem that, there is a single possibility for the future (Geltner and De Neufville,2018). Although many scenarios can be created based on a single stream of cash flows, it fails to consider the volatility of the underlying variables. Academics repeatedly mention that a stand-alone DCF model does not consider this volatility adequately. However, supplementary analysis such as scenario and sensitivity analysis informs on the deviations of the output values obtained from a static DCF model. According to de Neufville and Schotles(2011), these scenario analyses consider a range of values without analysing the likelihood of occurrence in a probabilistic manner. To consider the uncertainty within the project environment, the cash flow streams should consider the impact of these uncertainty variables. Such a consideration can be said to allow for accounting for a variety of possibilities and scenarios which eventuate based on a certain likelihood. These drawbacks stem from a deterministic modelling practice rather than just the use of static DCF techniques.

The range of future scenarios and a dynamic project environment is also made further complex by the uncertainty subjected due to the long period of development and construction before the phase of operation commences (Van Rhee et al.,2008). Considering that infrastructural development consists of such prolonged periods of construction and operation, a deterministic DCF model denies the decision-maker from valuing strategic decisions with flexibility. Smit and Trigeorgis(2006) claims that the utilization of DCF models for valuing strategic decisions is often short-sighted. Strategic decision making involves making choices that allow organizations to capitalise and forego their plans. Infrastructures consisting of high societal and strategic relevance (especially ports) can be understood to exist in a complex socio-technical fabric that demands a dynamic decision process. This dynamic decision-making process should allow for flexibility and allow careful positioning which lets the concerned authorities tap into the cash-flows being obligated to commit to an investment. To account for these uncertainties, RO is seen to be a suitable methodology to deal with long term projects which are riled with uncertainties (Dixit and Pindyck,1994).

1.2.2. Premise for Real Options Analysis for infrastructural decision making

The use of RO in infrastructural decision making might help a manager to make use of new information and help in overcoming a deterministic based valuation methodology. Furthermore, ROA can be seen to create flexibility within managerial decision leading to staged investment cycles (Smit and Trigeorgis,2006). RO at its crux, is said to give an investor the right to invest but not the obligation to exercise the investment decision (Peters,2016b) (Myers and Brealey,1995) (Cox et al.,1979). Hence, the options of deferring, ceasing and expanding on investment are possible within the framework of RO theory (Guthrie,2009b). This does not imply that these options cannot be engineered within a DCF model. For instance, the decision-maker can have planned stage gates to expand based on the availability of new information. However, ROA presents a rather formal methodology that allows for probabilistic calculation and optimisation. Through ROA the actions are formalised into options that can be adapted based on the planned stage gates for the investment decisions (Peters,2016b).

However, in reality, the governments who are involved with the decision making for large infrastructural decisions employ a DCF calculation which makes them commit to the investment, which leaves them with very little or negligible buffer to reverse the investment decision (de Langen et al.,2018). DCF analyses inherently assume that the decision-makers commit to the investment and all future cash flows do not change (de Neufville et al.,2005). However, these future cash flows are subject to changes based on the changes in the project environment. For instance, within the present maritime sector, it is observed that technological breakthroughs (automation, digitization etc.) are dominating the current demand patterns (van Putten and MacMillan,2005)(Taneja et al.,2011). Changes to these demand patterns are said to increase the volatility of the cash flows (both costs and revenue) (van Putten and MacMillan,2005). de Neufville and Schotles(2011) argue that it is the flexibility within systems that helps in protecting the system from these trend breakthroughs and aids in exploiting opportunities that develop in the future. In literature, it is shown that the value of flexibility and valuing investments stochastically allows a manager to exercise flexibility (de Neufville et al.,2005). van den Boomen et al.(2019), showed that ROA allows to capture market uncertainty and exercise flexibility throughout the decision-making process. It was also additionally remarked by van den Boomen et al.(2019), ROA provides an incentive for waiting for the new information disclosing. The incentive lies in the option to optimise future decisions based on the availability of information (van den Boomen et al.,2008).

1.2.3. Why Real Options Analysis for Ports?

According to Dixit and Pindyck(1994), it is claimed that an organization committing to an irreversible investment decision denies itself of the opportunities to make decisions based on the unravelling of new information in due course of time. The statement made by the authors can be seen to be truly applicable in port investments. Port investments are largely irreversible and require a commitment to investments within the various stages of technical design and master planning (Taneja et al.2012).

A classical view of the capacity expansion includes a continuously increasing time series of demand. These classical models do not include all the real-time complexities. Contracting expansions, gaining more time and postponing investments are some of the strategies employed by stakeholders in the current day. Especially, these strategies are useful to manage the influence of the uncertainties on the financial viability of the project. Uncertainties within the maritime are contextualised, as the variations in vessel sizes, throughput volumes, changes in the competitive landscape, environmental regulations, trade routes and political outlook. These uncertainties outlined by Taneja et al.(2011), might influence the future pay-offs. To consider these uncertainties, there is a requirement for dynamic and adaptive models. The DCF model on its own does not offer the opportunity to consider dynamic fluctuations in throughput volumes, alternative expansion strategies and staging capital outlays. The mentioned uncertainties play a significant role in capacity planning for ports. According to Meersman and Van de Voorde(2014), operational capacity is a crucial point of discussion for port authorities. According to the authors, failing to meet the demand (moments of under-capacity) leads to higher costs due to congestion and queuing. Immediate capacity expansions do not prove to be a feasible solution, due to the long planning and construction times. On the other hand, Meersman and Van de Voorde(2014) states that planning for excess capacity is another strategy. This strategy involves large magnitudes of expansion which is said to be long-term planning strategies. However, these strategies come with the burden of financing, idle capacity and higher average costs. Notteboom(2021) mentions the need for balancing the short term and long term planning activities. De Neufville (1991) and de Neufville et al. (2005) herald the potential of ROA in capacity expansion problems involving demand uncertainty.

It can be argued, structuring capacity expansions in a multi-stage manner can allow for the active management of long-term ambitions. Balliauw et al.(2019b), argues that decision-makers can consider, analyse and assess the influence of uncertainties on port development objectives through the implementation of ROA. Maaskvlakte-2 is said to qualify as one of the examples of a multi-stage expansion plan wherein part of the planned terminals and water basins were realised in the first phase. The second phase is said to be contingent on the capacity bottlenecks, thereby requiring additional terminal capacity (Balliauw et al.,2019b).

Formalising the multi-staged expansion of Maaskvalte-2 in terms of options and valuing the options for managerial flexibility can be said to be derived from ROA. The reason for applications of ROA in port infrastructural decisions stems from the flexibility given to the decision-maker to exercise expansion plans based on the influence of modelled uncertainties. ROA allows for decision rules and stochastic solving techniques which can allow the decision to develop to exercise project plans at moments where total payoffs can be maximised. Finally, ROA allows the decision-maker to carry out an integrated assessment wherein alternative strategies can be calculated and analysed through the number of paths generated by the considered volatility parameter

Finally, decision making for port infrastructures involve huge upfront costs, long payback periods, relatively long periods of development and construction (de Langen et al.,2018). ROA is typically implemented for such investments. Additionally, the financial viability of a port development or expansion decision is heavily influenced by future projections of demand. In many cases, these demand projections do not display the shock(s) surrounding the projection. One such example has been visualised in Figure 1.1. It illustrates a plot that compares the actual and the forecast values of demand for a port in Africa (Japan International Cooperation Agency,2009). It can be understood that the actual throughput demand has shocks that are not adequately matched by the forecasted values. ROA addresses these shocks in demand through considering market uncertainties through a stochastic approach (Taneja et al.,2011). Within other infrastructural operations and maintenance applications, it is shown that RO, allows for an optimisation which can help to address the needed flexibility within the consecutive intervention strategies over different periods (van den Boomen et al.,2020).

Therefore, the nature of investments and sources of uncertainties, make port infrastructures a worthy candidate to be investigated using ROA.

1.2.4. Research Gaps

- *Research Gap 1: Methodological Gap*

  Even though Real Options is gaining relevance within other infrastructural applications (For instance van den Boomen et al.(2019), van den Boomen et al.(2020) and de Neufville et al.(2005)). The application within port investments is seen to relatively lower. It is also observed that the application of RO varies based on the infrastructural application and the methodology varies based on the decision objective or problem. Balliauw et al.(2019b) presents a framework for implementing ROA for port investments under multiple uncertainties through a simulation approach. On the other hand Lagoudis et al.(2014) present

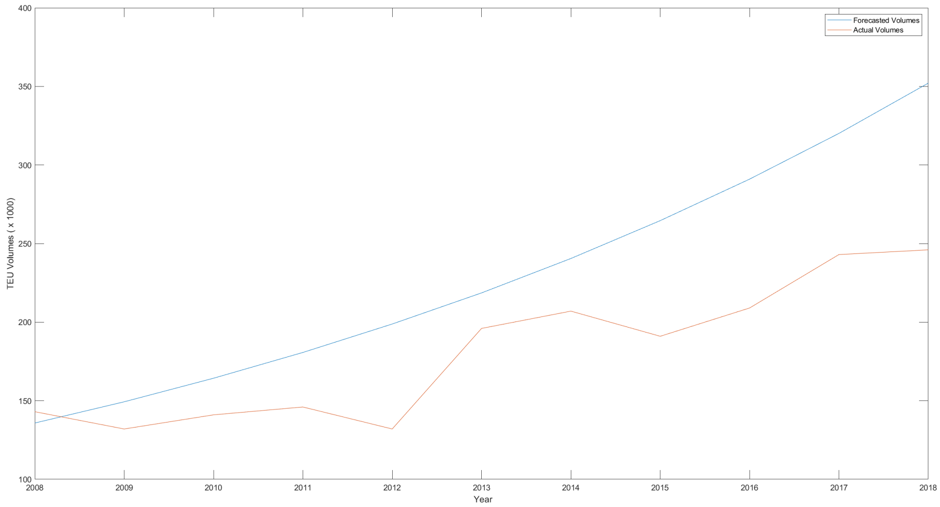

Figure 1.1: Perils of Deterministic Forecast
A linearly increasing forecast fails to represent the complexities and the shocks of the actual throughput volumes. Cases consisting of such weak forecasts which present a single-point estimate of the future might be undesirable when it is used to calculate cash-flows. These cash-flows might either under or overestimate the projections for financial viability.

their two-staged model involving a screening model and a Monte-Carlo simulation model to apply RO. The assumptions of the underlying approaches of the mentioned applications seem to vary in terms of the considered discount rates and calculation methodologies. Although Martins et al.(2017), Taneja et al.(2011) Salminen(2013) and Smit(2003), use real-time port infrastructure case studies, the mathematical models presented within these articles, varies in terms of the mechanics to value an option. Therefore, there is a significant number of approaches are implemented in port infrastructural decision making presenting the “added value of real options”. However, there is an underlying ambiguity in the mentioned approaches. Either the specified methods are theoretical or they do not represent real-time complexities or there is a myriad of approaches presented.

Therefore, this research attempts at filling the gap between various existing methodologies and present a conceptual framework along with an operational mathematical model which can be generalised for a port expansion problem[1].

- *Research Gap 2: Knowledge Gap*
A lack of clarity in the requirements for implementing ROA for port decisions problems presents a knowledge gap. The requirements for Options pricing have been prominently mentioned within academic finance texts. Additionally, RO for R&D projects and Oil& Gas present the value of ROA applications in terms of what options thinking represents. And what is the influence on the business case by using ROA? However, within port expansion problems, the process mechanics and nuance assumptions have limited discussion. **Through this research, the process mechanics, theoretical assumptions and requirements are appropriately listed. Sufficient argumentation around the influence of ROA around the business case will be developed using a case study as a test bed.**

- *Research Gap 3: Evaluation Gap*
The current wealth of literature suggests that the proponents of ROA seemingly agree with the value of the concept. However, the relevance of ROA in case-study and practice-oriented studies is limited (Triantis,2003). Herder et al.(2011) present the barriers for implementing ROA in real-time cases. Some of the barriers include complex mathematics, weak context and the amount of theory involved. Triantis(2005) mentions that, RO approaches prove to be theoretical thereby limiting its practical acceptance. Practice-oriented approaches of Copeland and Antikarov(2001) herald over-simplified approaches of ROA as the holy grail for valuing decisions concerning real assets. **The current research takes a balanced approach to assess the relevance of ROA for modelling port decisions through**

[1] Due to the variance in nature and the number of uncertainty factor, approaches are observed to be limited and confusing. This could be one of the reasons that, the current approaches are difficult to be generalised into one holistic framework.

the use of a test case study. Such an approach will allow for evaluating whether there is a presence of a practical value. Additionally, through the analysis of the results, the fundamental questions of usability, practical relevance, drawbacks of ROA will be discussed to address the gap of evaluation.

1.3. Agenda of Research

This section explains the theoretical design of the research. Firstly, within subsection 1.3.1, the objective of the research is explained. Secondly, subsection 1.3.2, presents the research questions tackled within the current research. Thirdly, the motivation and the relevance of this research are described in subsection 1.3.3. Finally, subsection 1.3.4 highlights the boundaries of the research.

1.3.1. Research Objective

The research objective for the research is :

To investigate the potential of implementing a RO based financial model for port infrastructural decision making by:

- *Extracting* the potential sources of uncertainty through exploratory interviews and literature review.
- *Devising* a conceptual framework (requirements and process specification) for conducting ROA within port infrastructural context.
- *Developing* an operational RO model based on the conceptual framework using real-time data from an existing real-life port.
- *Measuring* the potential benefits through a comparative analysis of the existing Discounted Cash Flow-based valuation model and the developed real options model.

1.3.2. Research Questions

Within this subsection, the research questions to be answered within the current research is presented. The main research question is formulated based on the over-arching research objective. A set of sub-research questions are constructed to answer the main research question.

Main RQ: ***What is the potential value of implementing Real Options Analysis within port infrastructural decision making?***

Sub RQ-1 intends to develop the context and present the required concepts on RO theory applications. Within the scope of this question, the methodology and the shortcomings of applying ROA within an infrastructural context will be elucidated. This can be said to aid in developing the conceptual framework.

- **Sub RQ-1**: What can be learnt from the approaches of Real options Analysis and its applicability on infrastructural decision making?

Sub RQ-2 narrows the scope to port infrastructural decision making and focuses on developing the knowledge base of the approaches, option mechanics, assumptions and workings of ROA in port infrastructural decision making.

- **Sub RQ-2** : What are the currently used process mechanics for modelling through Real Options Analysis specifically for port infrastructural decision making?

Sub RQ-3 aims at understanding the nature of port infrastructural decision making from the point of view of experienced industry professionals. Conducting exploratory interviews with experts can be said to help in the interpretation of the complexity of port planning and will further aid in extracting the relevant factors of uncertainties. Finally, the answers from this sub-research question create an additional context for discussion on the applicability of ROA under existing circumstances within the practice.

- **Sub RQ-3**: What is the practitioner's perspective on the parameters of uncertainty and financial valuation of port infrastructural decision making?

Sub RQ-4, will focus on implementing the resulting conceptual framework derived in Sub RQ - 3 for the chosen case study. Based on the availability of data, business case and project indicators, the numerical model of RO will be tailored. Through, Sub RQ-4 an understanding of the pros/cons and the feasibility of the theory of ROA within a real-time port will be developed.

- **Sub RQ-4**: How does the published implementation approaches and the requirements lead to a real options application for port infrastructures?

The final Sub-RQ focuses on the evaluation component of the research. The evaluation consists of a comparative analysis that allows for measuring the potential benefits of implementing ROA within the port infrastructural decision-making context. Additionally, this Sub-RQ focuses on the limitations and barriers of using a RO model against a conventional DCF model.

- **Sub RQ-5**: What can be derived from the comparison of the traditional valuation with the suggested model of real options within the context of the current case of port expansion?

1.3.3. Relevance and Motivation for the Research

Infrastructural investments involving huge upfront costs and expansion decisions that are irreversible can be said to induce complexity in the decision making process. Ports as an infrastructure involve high societal value as it presents with growth opportunities for countries and helps in countries to carry out a trade (de Langen et al., 2018). Investments within the port infrastructure are also said to be strategic as it allows for a country to capture more market share (Balliauw et al., 2019b). To materialize these strategic and financial objectives, the governments require an operational model which allows them to plan based on a variety of measurable outcomes. ROA which finds it foundation from the world of finance, has been claimed to be capable of handling uncertainties through options thinking (Smit and Trigeorgis, 2006)(Herder et al., 2011). ROA is said to provide the decision-maker with the flexibility to consider a variety of project-related outcomes. This flexibility will enable for exercising informed decisions and execute calculated responses for adaptation in the cases of sudden technological, political, competitive and financial challenges (Smit and Trigeorgis,2006). However, governments relying on the current DCF models are obligated to commit to an investment thereby making it difficult to capture the dynamic nature of project-related growth characteristics (Smit and Trigeorgis,2006). This is not only limited to public actors but private actors too will be limited by the use of deterministic modelling practices. Herder et al.(2011), claims that flexibility is seen to be a threat within port infrastructural decision making[2]. Additionally, Herder et al.(2011), remark that uncertainty within port valuations is considered by developing various scenarios against the base case NPV. The various scenarios are said to test business case and more often the decisions are made against the base case value.

The above-made claims within section 1.2 and subsection 1.3.3, might suggest that the current practices of valuations through DCF is inefficient for considering uncertainty and fails to capture flexibility. However, the current practice at Royal HaskoningDHV suggests that techniques such as sensitivity analysis, expert judgement, scenario analysis and probabilistic models along with the conventional DCF allow for the consideration of uncertainty. Additionally, it has also been observed that the consultants at Royal HaskoningDHV, advise the maritime clients (governments and private actors), to expand with phasing options[3].

The central interest point for this research is to understand, operationalize and study the potential benefits offered by a dynamic form of valuation which allows for flexibility within decision making. Furthermore, it is valuable to understand if the implementation of ROA provides any additional benefit which cannot be achieved using the existing methods of probabilistic models, scenario analysis and sensitivity analysis. The design and the evaluation form of this research can be said to result in a RO model which is contextualised to the factors of uncertainty for a real-time port expansion problem. Additionally, the development of an operationalised RO model through the theoretical foundations, allows for contributing a practical framework to the existing pool of literature. The current research reports the potential benefits of applying RO based on real-time complexity, which allows for evaluating the results critically. The comparative analysis and the validation interviews with experts can be expected to provide insights into the relative benefits of ROA over the existing practices.

From the above-mentioned research gaps, it can be understood that, although there is consensus on the concept of RO, the variety of methods makes the application of RO within specific applications confusing and

[2] The threat pertains to controlling the project within the cost and the time limits.

[3] Further explanation and description over the existing methods to account for uncertainty at Royal HaskoningDHV is presented in chapter 4

cumbersome. Hence, this research allows for the exploration of a variety of methods, followed by customization based on data requirements. **Finally, critical evaluation of ROA within port infrastructural context allows for the following contributions which will be scientific relevant:**

- ***Contextualised* factors of uncertainty for port infrastructural decision making based on the perspectives of practitioners and previous works within ROA.**
- ***Customised* conceptual framework of RO models based on the complexity of the chosen case study. The customised framework will allow for developing clarity within the existing method. Furthermore, it can be said to present the pros/cons of the variety of methods based on the relevance to port infrastructures.**
- ***Evaluation* of results from the operationalised numerical model of RO for a real-time port. The evaluation will aid in further identification of potential benefits and barriers in applying such a methodology.**

Gurara et al.(2018) present that increased infrastructural investments propel economic development within countries. Therefore governments and other private actors must strengthen their infrastructural investment strategies to ensure that such capital intensive with a long payback period does not end in inefficient project outcomes and ultimately become a burden. Through this research, the consideration of the dynamic growth characteristics can allow governments and other private actors to explore options of scaled investment and divestment strategies. The model which is developed considers the existing parameters within the DCF model from a stochastic perspective. Such consideration will result in a dynamic port expansion problem which eventualizes to further development of opportunities for descriptive strategic planning. The governments will now gain the option to adopt these decisions based on the future point of time. Such incorporation of flexibility within the valuation model can be said to be relevant for governments as it might allow for value creation stemming from informed decisions based on the behaviour of the dynamic parameters. Finally, the research is positioned to use real-time data and a numerical approach. This kind of perspective is an attempt to make this research relevant to the practitioners as well.

1.3.4. Scope of Research

The focus points of the research are to design and evaluate a RO model for port infrastructural decision making. The RO model which is to be designed uses data from a port expansion case study of port which is situated in Africa[4]. **The current research uses the current wealth of approaches for ROA applications as a guideline for design. Additionally, the model which is proposed within this thesis is made relevant for the complexities and the variables of the chosen case study. This will ensure that the devised framework is practically relevant and addresses the methodological gap.**

The case-study data involves the background of the port expansion and its corresponding DCF financial model. **To achieve the evaluation component of this thesis, the business case of the Port Authority of Toasmasina is considered as a test case and the operationalised RO model is contrasted against the existing DCF model.** For carrying out an in-depth investigation of ROA within port infrastructural decisions, the focus is narrowed down to port expansion problems. The port expansion problems are investigated by analysing for the optimal time moments and magnitudes of expansion. At these optimal time moments, the port authorities should consider expanding the port with the calculated magnitude of the expansion. These decision problems are investigated using the case study. Additionally, the numerical approach ROA is also used to calculate the value of flexibility for flexible expansion strategies. This allows for understanding whether a staged expansion has a monetary value. Moreover, investigations such as When does flexibility has a value? For which expansion options flexibility has value? are carried out.

Through the analysis for optimal time moments, magnitudes and value of flexibility the potential benefits of ROA will be determined. In conjunction with the discussion of this analysis and a limited validation, the drawbacks of ROA in port infrastructural decision making will be highlighted. The data from the DCF model for the case study is used as a base estimate and will be compared against the devised RO model. Finally, based on the results of the case study implementation, the results will be further generalised to decision making using ROA. Such a scope will aid in contributing to the knowledge pool.

[4]Additional description on the specifics of the case is provided in chapter 4.

1.4. Report Outline

This section presents the overall narrative of the report. The overall report outline for the report is visualised in Figure 1.2. In all the required chapters, at the start of the chapter, a brief on the relevant takeaways and their relation to sub-research question are provided. Similarly, at the end of the chapter, the relevant takeaways from the chapter and its utilization in further chapters are provided.

The overall research methodology for this research has been described in chapter 2. Within this chapter, the four distinct phases of the research are highlighted. Additionally, the motivation for each phase and its explanation is provided. The explanation of key terms and the foundational theoretical background for the research are provided in chapter 3. The existing methodologies for ROA are discussed. With the description of each method, the author's critiques are also presented based on cited literature. Moreover, the current implementation approach for ROA in infrastructural and port infrastructural decision making is discussed in detail. The summary of current implementation approaches within infrastructural articles is tabulated in Table 3.4. Discussion of these articles allows for understanding the implicit assumptions, advantages and limitations of the ROA methodologies.

The results of the Exploratory Interviews and Case Data Exploration are described in detail in chapter 4. The insights from the exploratory interviews especially regarding the uncertainty parameters are used while devising the conceptual framework. Additionally, some of the insights are also discussed in the discussion section of the report. The Case Data Exploration describes, analyses and discusses the case of African Port in detail. The results of these analyses are used for comparative analysis in a further chapter of Results.

The devised conceptual framework and the numerical model of ROA for port decision making are presented, explained and reasoned in chapter 5. This is partly achieved by, using the takeaways from the theoretical background presented in chapter 3. Additionally, the insights from the interviewees present in chapter 4 are also used to reason some of the assumptions within the conceptual framework.

The results and analysis obtained from the implementation of the numerical model of ROA for the case of African Port are presented in chapter 6. These results are recorded from the setup of the model mentioned in chapter 5. This chapter presents the analysis to identify the optimal adaptation route. Additionally, the monetary value of flexibility has also been calculated in this chapter. Finally, a comparative analysis between the static DCF and numerical ROA has been presented.

The results and analysis are further discussed in chapter 7. Firstly, the current results from the research are discussed under the context of previous research. Finally, the implications of the results on the objective and research gaps of the research are addressed within this section.

Based on the results, analysis and discussion, the conclusions for the research is explained in chapter 8. Within this chapter, the answer to all the sub-research and research questions have been answered. Finally, the limitations and recommendation arising from this research have been listed.

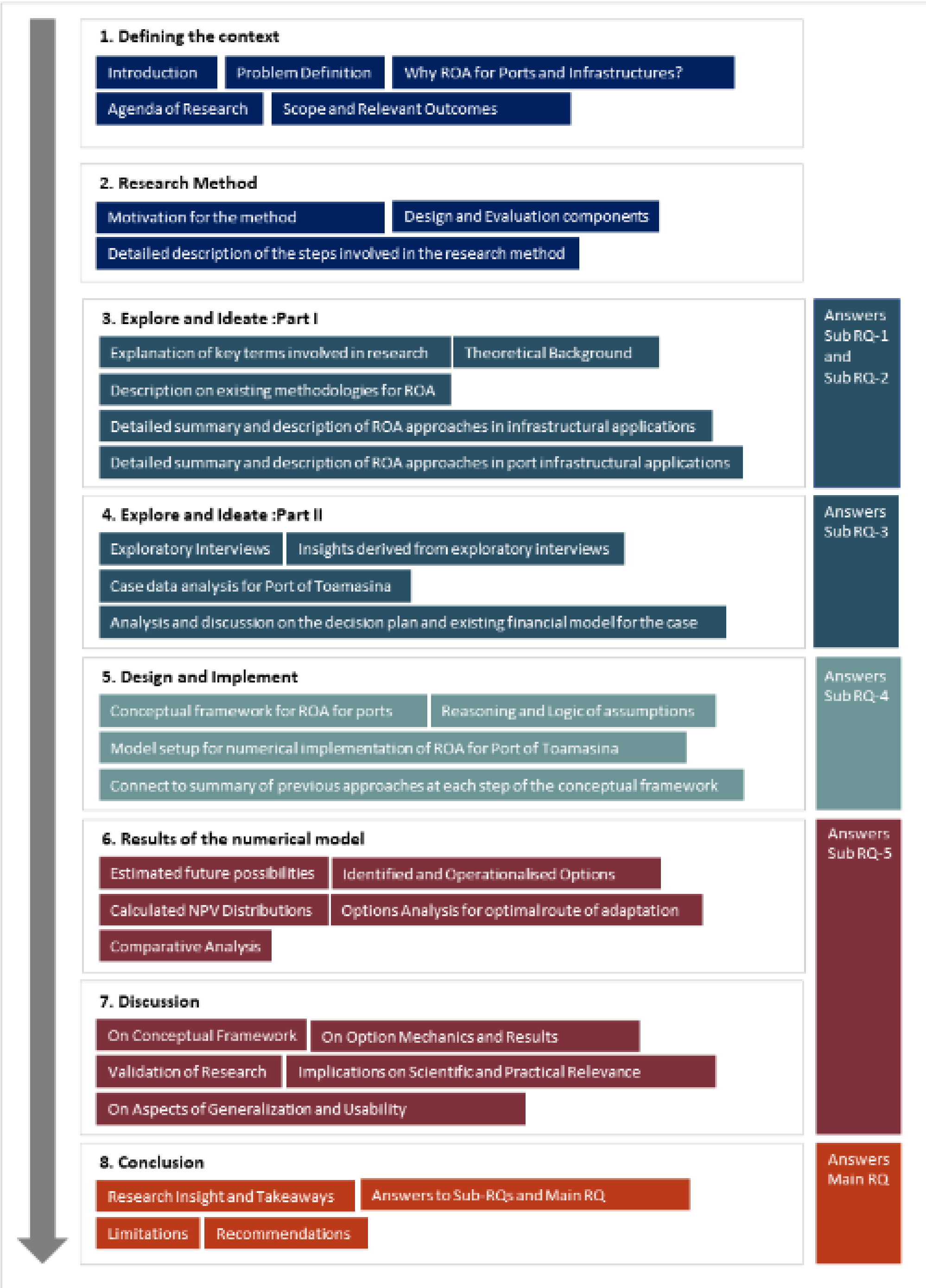

Figure 1.2: Overall Report Outline indicating the key contents within each chapter and its relation to the research questions.

2
Research Method

There are so many ways to account for negative outcomes that it is safer to doubt one's methods before doubting one's subjects.
— Frans de Waal

This chapter explains the research methodology that is adopted for conducting the research. An innovation funnel approach consisting of four different phases is adopted. These four phases are comprehensively explained in terms of their process particulars, relevance, the anticipated outcomes and their link to the research questions.

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2. Research Method

Motivation for the method | Design and Evaluation components

Detailed description of the steps involved in the research method

2.1. Introduction
This section presents the particulars of the research method. Specifically, the motivation of the selected methods and a high-level description of the methods are explained. The following sections consist of reasoned explanations based on the specific step of the research methodology.

2.1.1. Motivation for the Method
The current research follows a combination of design and evaluation based research. The motivation for choosing such a combined methodology is two-fold. Firstly, the current wealth of literature does not present a clear framework or a blueprint of applying real options to a case of port infrastructural decision making[1]. Through the design component of the research, these varieties of methods have been explored and contextualised to the port infrastructural decisions (and especially to the chosen case study). An operationalised numerical RO model is the result of the design phase. Secondly, the evaluation part of the research focuses on assessing the relevance and the potential benefits of the implementation of ROA within port infrastructural decision making.

2.1.2. High-Level Description of the Method
The research method for the design and the evaluation oriented research is illustrated in Figure 2.1 and is executed in four distinct phases. According to Verschuren et al.(2010), design-oriented research allows for

[1] Within subsection 1.3.3 it is presented that, there is an agreement over the potential and the concept of ROA. However, the concept of RO has been applied using a variety of methodologies, thereby creating ambiguity within the methods to be applied for specific applications.

formulating a practical plan which can be used as an approach to the problem. Additionally, Verschuren et al.(2010) remarks that evaluation research involves assessment based on a list of criteria to compare and contrast the results. Combining these concepts of design and evaluation oriented research along with an innovation funnel fits well within the objective and scope of the current research. Because it allows for designing a numerical ROA model through exploration, ideation and development. And allows for evaluation through implement and evaluate phases. Figure 2.1 depicts the intended methodology to be incorporated within the course of this research.

The Explore and Ideate form the first phase of the research wherein the topic and the methodologies are explored. In conjunction, with the exploration, the potential methods of implementing ROA were studied. This phase intended to develop a strong context wherein further research can be developed and carried out. This phase involves consulting the recent literature on the application of ROA within infrastructural systems and understand the arguments related to the potential benefits or value presented by its application. Further to this, the theory of RO is studied closely under the context of port expansion decision making. Finally, the exploratory interviews and exploration of case data also form other essential blocks of this phase. The information obtained within this phase serves to act as the input for the subsequent phase of Develop.

The Develop phase involves developing a conceptual framework for the application of RO within port infrastructural investments by making use of the results obtained from the desk research. The conceptual framework allows for the design of the numerical model which is contextualised to the specifications, requirements and data of the chosen case. The chosen case study involves the African Port wherein the organisation was asked to structure a financial model which will help the port authority to negotiate a new concession agreement for the period of 2025 - 2035. The port authority is planning for a capacity expansion from 2025, which is said to take 8 years to complete. As a part of the assignment, the organisation developed a financial model concerning the business case of port authority and operator. The business case of the port authority is chosen to be a suitable case for the implementation of ROA as it is built around single-point estimates, constant increasing trend of forecast volumes and consists of an inflexible expansion plan. Additionally, this case study presents itself with an underlying static DCF model which allows for the further implementation of the ROA approaches.

The third and fourth phase involves the elements of evaluation oriented research. This is done by analysing the impacts of a ROA model on the results. The third phase of Implement allows for the application of the RO model under the context of a real-time port expansion problem. This phase allows for the check of computational coherence and the relative potential benefits offered by the designed model.

The final phase of the research involves the evaluation of the numerical model and the conceptual framework. To assess the potential benefits of the ROA model, it is compared against the existing inflexible strategy in place. Moreover, the flexible strategies are quantified for their options which allows in determining the value of flexibility within the scope of the case study. Finally, through analysis of the option mechanics and comparison of the results to previous works will contribute to the evaluation. A limited validation with experts will also contribute to the evaluation of the conceptual framework, numerical model and its accompanying results from a practitioner's perspective.

Based on the results of the evaluation phase, the results will be then generalised to other applications within other infrastructural networks facing uncertainties.

2.2. Explore and Ideate

This phase involves three sub-sections which are focused on developing the foundation for the further part of the design-oriented research. The details of this phase are illustrated in Figure 2.2. The first section called the theoretical background is focused on understanding the concept and methodology of ROA. Following this, the section on Exploratory Interviews presents a practitioner's perspective on the current aspects of port planning and the port infrastructural decision-making process. Finally, the case data which is used within this research is described and discussed.

2.2.1. Theoretical Background

Within the context of the theoretical background, the required knowledge for executing the design part of the research is presented. Specifically, literature review as a form of desk research is used to gather and summarise the state-of-art literature on the topics of RO and its application within infrastructural systems. Through this step of the research, the focus is maintained on understanding the background and the methodologies involved within the numerical works on real options theory. Additionally, studying the implementation of real

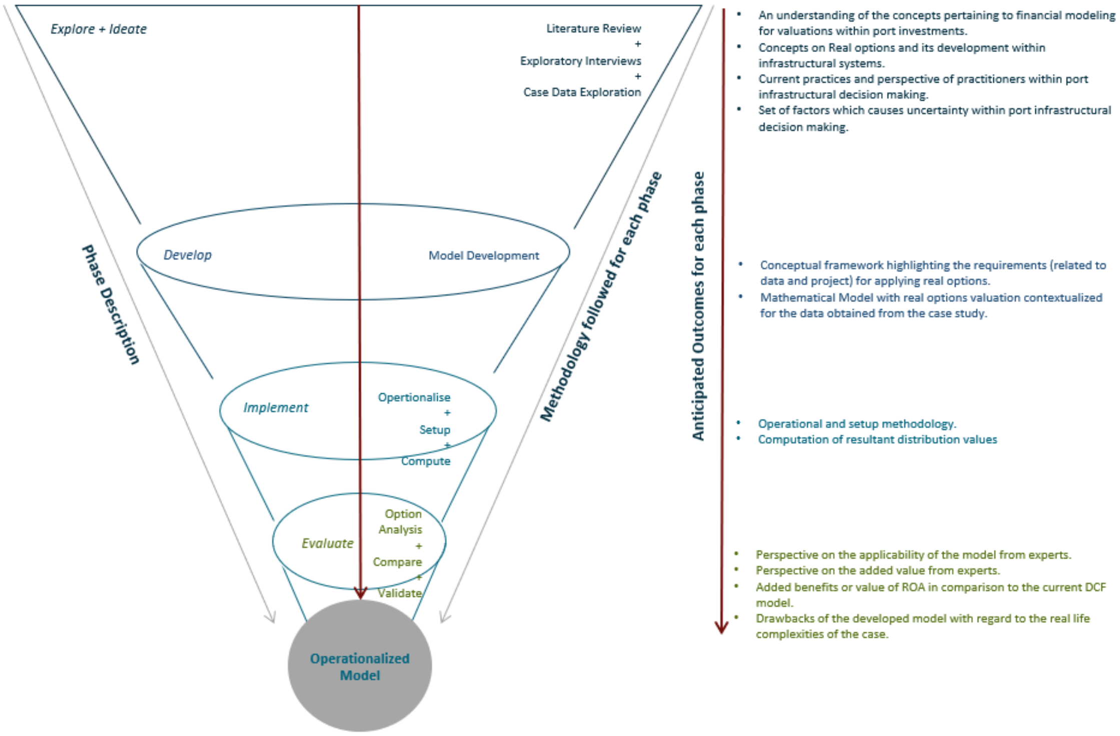


Figure 2.1: High-Level Research Method using an innovation funnel approach.
The innovation funnel approach allows for narrowing of the solution space as the research progresses. Once the numerical model is implemented and evaluated, the results are then discussed for its broader implications.

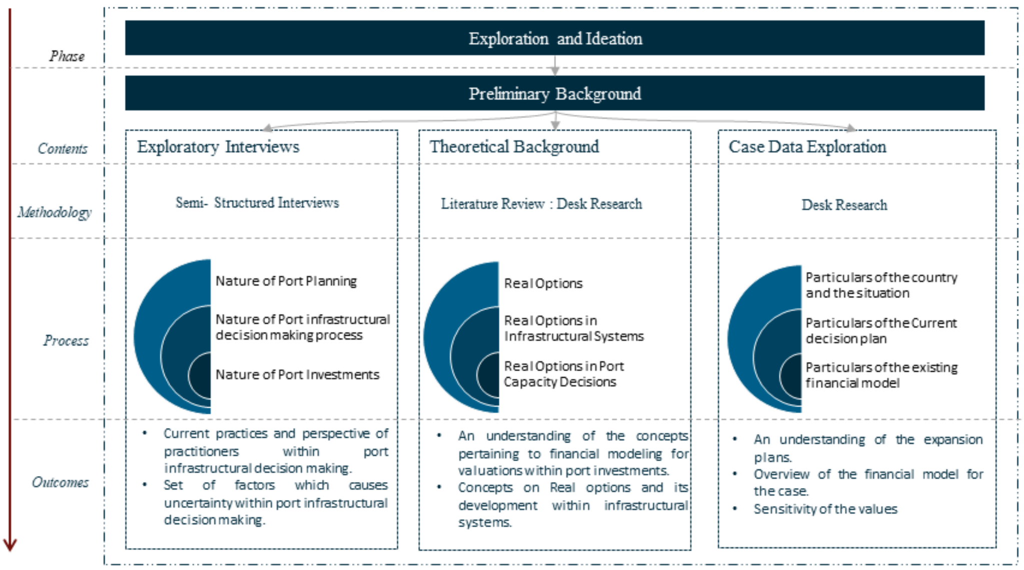


Figure 2.2: Specifications for Explore and Ideate Phase
The Explore and Ideate phase involves understanding the breadth of applications of ROA within the literature. Additionally, it involves understanding the current practices of professionals through exploratory interviews. Finally, the data from the case study has been analysed and discussed in-depth within the subsection of case data exploration. The figure highlights the process flow based on the anticipated outcomes for the first phase of the innovation funnel i.e. Explore and Ideate. .

options valuation within infrastructural decision making is of specific interest. The desk research involves a systematic literature review methodology based on the three-step process of Tranfield et al.(2003). It begins with the planning and relevance phase, wherein the articles are checked for their suitability with the current research objective. Based on the selected article a review is conducted as a part of stage 2. Finally, the inferences are drawn and reported in the final phase. The search for articles was restricted to the keywords of “real options”, “real options analysis”, “real options valuation” and “vale of flexibility”. The Boolean search was carried out using “real options analysis” AND “capacity expansions”, “real options analysis” AND “infrastructure decision making”, “real options analysis” and “port infrastructural decisions”, “value of flexibility” AND “infrastructural systems and “real options” AND “capacity expansions”. The major source through which the articles were searched included Scopus, Google scholar, TU Delft Library Portal.

2.2.2. Exploratory Interviews

Verschuren et al.(2010), claims that exploratory interviews are crucial for research involving a design approach, as it allows for understanding the current models or protocols. Additionally, aid in the widening of the solution space. Within the context of this research, exploratory interviews served three purposes.

- Firstly, it was used to obtain an understanding of the nature of port planning. As the author is not well versed with the nuances of port planning, such a session allowed for greater understanding.
- Secondly, it allowed for presenting the current dynamics involved in port infrastructural decision making.
- Finally, it served as a basis to understand the pitfalls of the traditional DCF models and the practitioner’s perspective on the consideration of uncertainty.

Bryman(2016), presents that qualitative interviews can be conducted as unstructured and semi-structured interviews. A semi-structured form of the interview will allow for both flexibility and focus on specific topics or themes. To extract insights within a said time, semi-structured interviews was observed to be a good fit for the nature of this research. A semi-structured interview involves the collection of data using interviewees from varied disciplines which allows for different perspectives to the open-ended questions (Bryman,2016)(Verschuren et al.,2010).

Table 2.1: Details of the Interviewees

Code	Role	Group
MA_EO_D	Director	Maritime & Aviation - Economics & Operations
MA_EO_AD	Associate Director	Maritime & Aviation - Economics & Operations
MA_EO_IA	Senior Investment Advisor	Maritime & Aviation - Economics & Operations
MA_PM	Project Manager and Port Consultant	Maritime &Aviation
MA_D	Director	Maritime & Aviation
MA_MA	Manager Auditor	Maritime & Aviation
MA_PC	Port Consultant	Maritime & Aviation
MA_PE	Project Engineer	Maritime & Aviation

The semi-structured interviews were conceptualised by making a list of potential interviewees within the organisation . This was done using expert sampling wherein experts from different backgrounds, focus lines and experience within the Maritime and Aviation group within the organization. Particulars of the interviewees are tabulated in Table 2.1. Bryman (2016), presents expert sampling as a methodology for interviews to include various perspectives within the line of research. Secondly, the interviews included questions on the nature of port planning, nature of port infrastructural decisions and nature of port investments. The interviews were planned for 45- 60 minutes. All the interviews were recorded and transcribed. Before the start of the interview, the research objective was presented. This allowed the interviewees to form a context and present their answers focused on the overarching theme of uncertainty within port development. The complete interview question protocol is presented in section 9.1.

2.2.3. Case Data Exploration

This section of Explore and Ideate describes the existing data obtained from a real-time project which was executed at the organisation . The chosen case study was the case of african port. The organisation had been commissioned to structure a financial model, which calculates the feasibility and cash-flows for the expansion plans. The model created by the organisation analyses the different conditions under which the planned investments will yield returns to both the parties involves i.e. terminal operator and the port authority. Based on the results of this financial model, the organization reports on the decision making for the port expansion which can allow the negotiation of a new concession agreement between the port authority and the terminal operator. The use of this case data forms the basis for the implementation of the RO model within a port expansion context. The objective of the section of case-data exploration is to present the existing business case accompanied by the relevant input data and output. Exploration of the case study will aid in setting the context for further research and allow for the analysis of the existing financial model.

Study Area

The case study port is located in an island country in the Indian Ocean. The port is connected to the capital of the country through rail and RN2(Route Nationale 2: a primary highway in the country). Shipping plays a major role in the country's good flow due to its island location within the southern Indian Ocean with a length of 1020 m and a depth of 12.0 m (Japan International Cooperation Agency,2015b).

Project Decision Plan

The project as seen by the authorities is set to increase the capacity as a response to the anticipation of growing cargo demands. By doing so, it is believed that the port can squeeze more productivity and revenues from the capacity expansion. Furthermore, it is also expected that such a capacity expansion will aid in streamlining the mineral resource logistics and also attract investments. The benefits of capacity expansions are finally expected to boost the economy of the country and establish itself as one of the key players within competing players within the Africa region (Japan International Cooperation Agency,2015b).

- Extension of the breakwater (up to 345 m in length).
- Construction of the container berth C4 with a length of 470m and a draft of 16.0 m.
- Extension of the container yeard (up to 10 ha).
- Deepening of the Container Berth C3 (up to 16 m in depth).
- Deepening of the Bulk Cargo Berths C1 and C2 (up to 14 m in depth).

2.3. Develop

The overall methodology and process particulars for Develop is illustrated through Figure 2.3. The results of the theoretical background and the exploratory interviews allowed for the design of a conceptual framework contextualised to the complexities of port infrastructures. As mentioned within subsection 1.2.4, this component of the research focuses on methodological gaps. Through the develop phase, clarity on the variety of methods within the requirements of a port expansion will be advanced. This conceptual framework of RO for port infrastructural decision making presents the requirements (in terms of data) and the process methodologies that can be followed. The requirements list is made as a two-step process. Firstly, based on the previous application of RO within port infrastructural systems a requirement and process mechanics list are made. Secondly, this list is then filtered based on the complexity and the particulars of a port infrastructural asset.

The conceptual framework is then put to use by numerically modelling as a ROA method of valuing the expansion decision. The conceptual framework along with modelling techniques obtained from the literature study is implemented on Microsoft Excel. At the organisation , the valuation is modelled on excel using the FAST principles(FAST stands for Flexible, Appropriate, Structured and Transparent). To allow for integration with current models, the RO model is created within the scope of these standards. The model development includes the three vital tasks which are structuring the inputs and options identification. Secondly, implementing the simulation of the uncertainty parameter. Lastly, calculating distributions of cash flows (which finally results in option values). The model development takes a numerical approach. The numerical approaches approach helps in simulating real-life complexities and help in providing conclusions through approximations (achieved through repeated simulations) (Peters,2016a). To ensure that, the tool works as designed, the computational coherence, result verification and sensitivity analysis are conducted within the implementation phase.

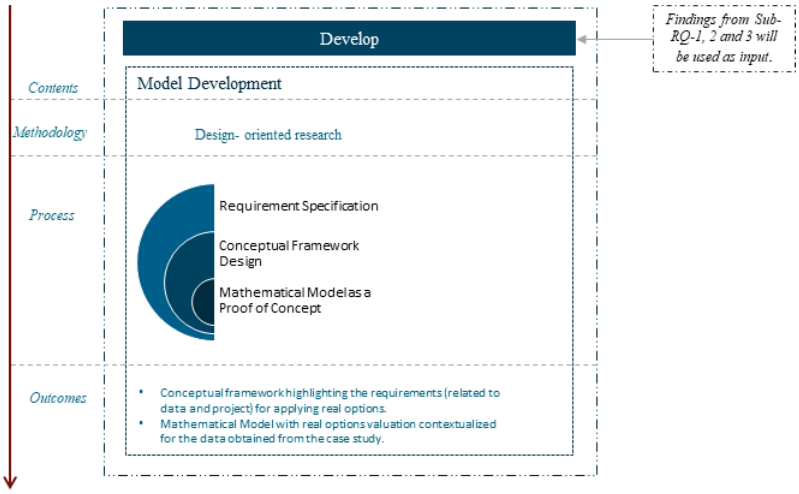


Figure 2.3: Specifications for Develop Phase
The figure presents the Develop phase of the innovation funnel. Within this phase, the scope is narrowed to port expansion decisions. The conceptual framework is contextualised to the complexities of port expansions and the case study. The conceptual framework is then put into use to build a numerical model for ROA for the case study..

2.4. Implement

Once the model is designed, it is then simulated and implemented in a practical real-time case of African Port. The objective within this phase is to record the results for further testing of the computational coherence, result verification, sensitivity analysis and conducting a comparative analysis. The implementation phase allows for understanding and presenting the benefits and the value of the application of ROA for a port expansion problem under a real-time setting.

2.5. Evaluate

This phase forms the last stage of the research wherein the designed real options model is evaluated for its added value through the comparative analysis between the strategies developed through the RO model and the inflexible strategies as derived from the static DCF model. The comparative analysis involves the comparison of the key outputs resulting from the designed model and the traditional DCF model. The options are also analysed for understanding the optimal time and magnitude of investment. Additionally, the option values are calculated and the value of flexibility has been calculated for flexible expansion strategies. the organisation has built a traditional Discounted Cash flow model for this case of port expansion within Madagascar which will be further used for comparative analysis. Additionally, the comparative analysis will contrast the key elements of the decision-making process involved in the two models. Additionally, the results will be compared to previous works on ROA and assess for the current work's contribution. The perspective of interviewees in the exploratory interviews are also compared and discussed with the results obtained from ROA. Finally, a limited validation will be performed to understand the significance, limitations and practical relevance of such a model. To conduct the limited validation, the company supervisors were interviewed together for 60 minutes. As both the interviewees are involved in financial modelling and advise clients on port development projects, their perspective on the conceptual framework, numerical model and results will be allowed for a brief validation. Particulars of the interviewees for the validation session are tabulated in Table 7.11. Finally, the lists of questions asked during the validation session can be found in section 9.2.

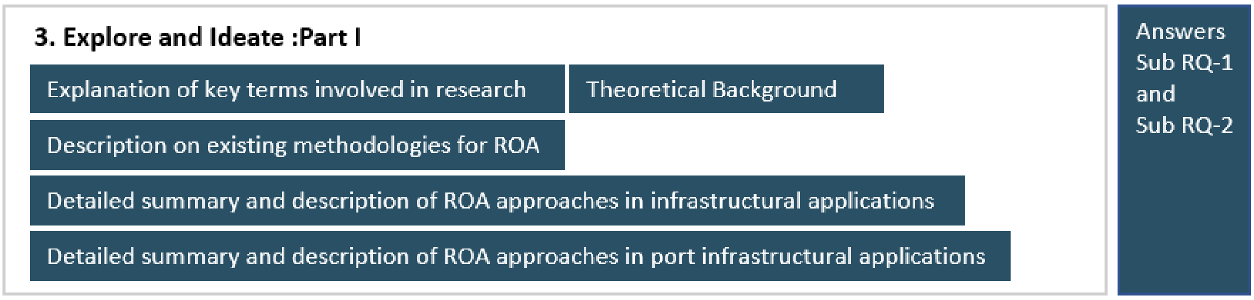
Table 2.2: Details of the Interviewees

Code	Role	Group
C1	Senior Investment Advisor	Maritime & Aviation - Economics & Operations
C2	Consultant	Maritime & Aviation - Economics & Operations

3

Explore and Ideate Phase - Part I

Antifragility is beyond resilience or robustness. The resilient resists shocks and stays the same; the antifragile gets better.
— Nassim Nicholas Taleb,



This chapter forms the first phase of the Explore and Ideate step. In this chapter, the knowledge context of the research is presented. The first half of the chapter operationalises the key terms which are relevant to this research. The second half includes a deep explanation of the theoretical background on which further research has been conducted. The relevant takeaways from this chapter include the following:

1. A summary of the approaches which are used for real options applications.
2. Discussion on approaches and process mechanics of relevant articles which are related to infrastructural applications.
3. The process mechanics, assumptions, methods and implications derived from the current implementation applications of ROA for port infrastructures.
4. Discussion on the validity of the current approaches for the current focus of research.

Through the above takeaways the following research questions have been answered:

- **Sub RQ-1**: What can be learnt from the approaches of Real options Analysis and its applicability on infrastructural decision making?
- **Sub RQ-2** : What are the currently used process mechanics for modeling through Real Options Analysis specifically for port infrastructural decision making?

The takeaways from the process mechanics of infrastructural applications especially for ports will be further utilized in chapter 5, for deriving the conceptual framework and the setting up of the model for the case study.

3.1. Preliminaries

Through this section, the major terms used repeatedly within this report is connected to its operationalised definition. This will allow the reader to have a consistent understanding which is in line with the context and the reasoning of this research.

3.1.1. Uncertainty and risk

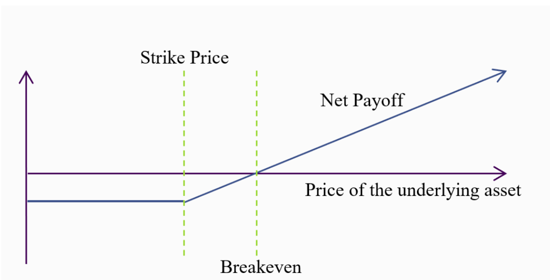
Walker et al.(2003), Park and Shapira(2018) and Dizikes(2010) point that, the formalised definition and distinction of uncertainty was provided by Knight(1921). Uncertainty is defined as an outcome of an event wherein the occurrence cannot be measured due to the paucity in knowledge in the present Knight (1921). Therefore, the event cannot be predicted with accuracy with current information. According to Knight(1921), the differentiation between uncertainty and risk is the ability to be quantified. Park and Shapira(2018) defines that, risk involves decision making where the set of potential outcomes along with their occurrence likelihood is known. Uncertainty and risk are often times used synonymously. However, within the academic literature, a quite number of discussion on the differentiation of these terms have been observed. For the context of this research, uncertainty is defined based on Walker et al.(2003) wherein, "uncertainty is any departure from the unachievable ideal of complete determinism".

3.1.2. Flexibility

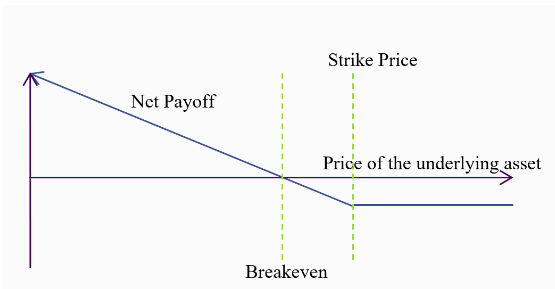
According to de Neufville and Schotles(2011) through exploiting flexibility, the manager adapts the system based on uncertain trends to derive maximum value from the decision. Wang and De Neufville(2005), makes a distinction based on the origin of flexibility. Flexibility "in" system involves the design team to design for adaptation. This involves the underlying asset to have the capability to be moulded based on its technical aspects. While a flexible "on" system involves the managers to adapt project progress or optimising existing operations (Wang and De Neufville,2005). For instance, transport operators can adapt their bus schedules based on the concentration of demand. More specifically for port decisions, port authorities can adapt their expansion plans based on the deviations between the real and the anticipated throughput volumes. In this research, flexibility forms an important aspect of RO analysis. It focuses on different combinations of expansion modules and operational decisions by accounting for variable growth.

3.1.3. Basics of Options

The concept of options has been seen to be consistent regardless of the case of implementation. From Myers and Brealey(1995), Trigeorgis(2005) and Damodaran(2000), an option is defined as the right but not the obligation to buy or sell asset at a specified price (called as exercise or strike price) on or before the set expiration date. Based on the nature of options, it is classified as call and put options.



(a) Payoff diagram for a Call Option



(b) Payoff diagram for a Put Option

The call option involves the situation wherein the buyer has the right but not the obligation to buy the underlying asset at a strike price before the expiration period. The option is worthless if the value of the asset is lesser than the strike price. And the option is exercised if the value of the asset is higher than the strike price. Figure 3.1a, shows the payoff diagram for a call option. On the other hand, the put option involves the situation wherein the buyer has the right but not the obligation to sell the underlying asset at a strike price before the expiration period. The option is worthless if the value of the asset is greater than the strike price. While the option can be exercised if the value of the asset is lesser than that of the strike price. The payoff diagram for a put option is shown in Figure 3.1b.

Options exist in our day to day lives. A simple example from Copeland and Antikarov(2001) involving a fictional situation wherein an individual is given two opportunities. The first involves a toy bank wherein one needs to put a dollar and receives 1.05 dollars after a year with complete certainty. The second opportunity involves keeping the money at a real bank that has a 10% interest rate. Figure 3.2 describes the example and its results in more detail.

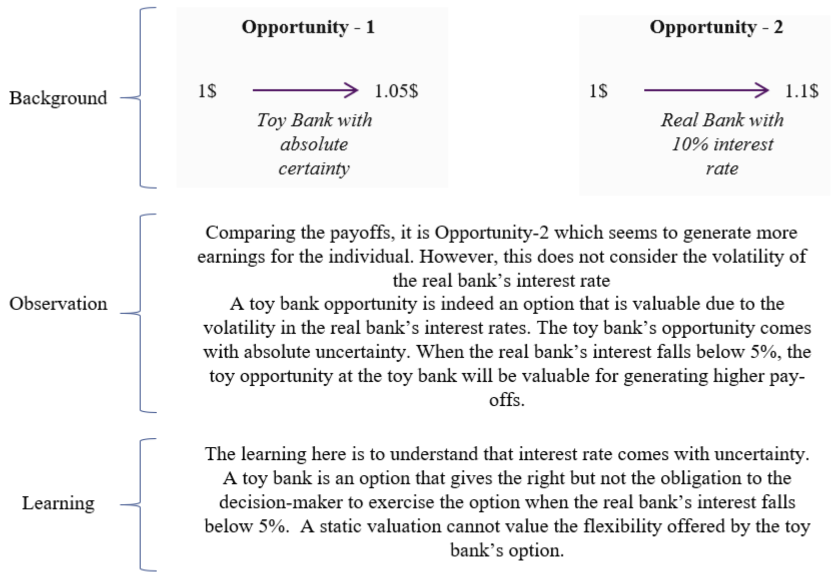


Figure 3.2: Example of options understanding (adapted from Copeland and Antikarov(2001)

3.1.4. Real Options

Extension of Options Pricing Theory to the financial valuation of "real assets" which are tangible are called real options (Myers and Brealey1995). Similar to financial options, within real options the decision-maker has the right but not the obligation to exercise the options. Similar to financial options, real options is a methodology that can be used to manage the uncertainty of the underlying asset. The methodologies used within financial options cannot be directly replicated to real options due to the nature of assets, issuing organisations and option constructs.

Financial options involve assets that are traded on the market, thereby allowing for estimating its variance from historical data or similar assets. However, in the case of the real option, the underlying asset is not directly traded(Myers and Brealey,1995) (Copeland and Antikarov,2001).Similar to flexibility "in" and "on" systems, RO too is differentiated in terms of "in" and "on" projects.

3.2. Theoretical Background

The merit of real options is its dynamic nature of valuation and the consideration of active management. Over the past 30 years, real options analysis has been implemented to investment decision problems which are not limited to new technology Copeland and Antikarov(2001), infrastructure De Neufville(1991), real estate Geltner and De Neufville(2018), gas field Guthrie(2009b). The concept of real options analysis is finding its relevance to create adaptation policies and create strategic foresight (van Putten and MacMillan,2005). According to Mun(2002), options pricing is especially interesting for real assets, as it gives the ability to reduce resource commitments and defer or scale or exercise investments based on the underlying volatility of the variable. Managing project decisions through real options analysis is also said to allow for managing uncertainty in a constructive manner which can result in minimizing the downside potential of the investment (Neely and de Neufville,2001). This is done by considering the future as a range of scenarios and develop optimal pathways through a range of outcomes. Within academic literature, the term ROA is seen to imply real options valuation (calculating option values) and real options thinking (qualitative reasoning). Within this section of the chapter, the focus is maintained on understanding the background and the methodologies involve within the numerical works on real options theory. Additionally, studying the implementation of real options valuation within infrastructural decision making is of specific interest. The desk research involves a systematic literature review methodology based on the three-step process of Tranfield et al.(2003). It begins with the planning and relevance phase, wherein the articles are checked for their suitability with the current research objective. Based on that the review (stage 2) is conducted which is then reported in the final phase. The search for articles was restricted to the keywords of “real options”, “real options analysis”, “real options valuation”, “valuing flexibility within infrastructural systems”. “real options in capacity decisions”. The major source through which the articles were searched included Scopus, Google scholar, TU Delft Library Portal.

3.2.1. Classification of Real Options

The concept of real options as a valuation technique differs from the idea that the investment decision is a simple go/no-go decision that is made upon the financial indicators of a DCF model. Rather the decision-maker can modulate the expansion size, or wait and see. The option to adapt operational and design decisions can be classified into four broad categories. These four categories are derived from the works of Trigeorgis et al.(1996), Myers and Brealey(1995) and Herder et al.(2011). Moreover based on the level of focus RO can be categorised in two categorised of in” and “on” projects.

1. **Based on Level of Focus**
   Geltner and De Neufville(2018) in their implementation of ROA within real estate planning differentiate between in and on based on the level of focus taken within the system. If the option concerns on the whole system it is called as options “on” projects (Wang and De Neufville,2005) (Neely and de Neufville,2001). Real options are applied “on” projects in the cases where the uncertainty is related to the markets factors e.g. changes in demand (De Neufville et al.,2004).

   On the other hand, if the option concerns a sub-component of a system especially related to the technical design aspect, then it is called an option “in” projects. Options “in” projects require deep technical knowledge and is more proactive planning which is developed with the designers (Cardin et al.,2007).

2. **Based on Application**
   Options should not be confused with opportunities or alternatives as it provides the right to take a certain step in the future step at a particular price. The project’s future course of actions can be described using many options, however, the following four are the succinct four options that find relevance especially within infrastructural applications:

   - Option to defer or staged market entry
     The decision-maker has the option to delay or defer investment until there is more clarity about the project’s future development. This could pertain to clarity within market development, forecasts, competitive activity. The options to delay or postpone the investment is a kind of American options wherein the exercise price is equivalent to CAPEX. Myers and Brealey(1995) shows that the polarity of NPV is not enough to consider the timing and the magnitude of investment. There is also another alternative that involves wait and see. A staged market entry involves phasing the capital investments (similar to many real-life scenarios) and create stage gates before each subsequent phase. In essence, by incurring capital outlay for each stage, the project progresses to subsequent stages and can be abandoned at any stage (Trigeorgis,2005). According to Herder et al.(2011), decision-makers need to ask: “What are the uncertainties which are relevant for this project? Would it be interesting to observe the developments in the market and invest later?” Asking such questions is said to help in recognising the additional value generated by the investment and add flexibility to further developments.

     Example in maritime: For the option to staged market entry, an example for port decisions as presented by Taneja et al.(2011) involves expanding the port in phases as a response to the anticipated growths of demand.

   - Option to abandon or shut down temporarily? or switch
     According to Peters(2016b) the abandonment decision corresponds to the put option on the project value. This option can be considered when the real-time cash flows do not match the expected cash-flow forecasts. The option to abandon or shut down temporarily is valuable within high volatility market. The option to switch is a good addition to the conventional abandonment option as it provides the decision-maker with the option to re-route the liquidated assets or existing resources into other innovative projects. Consideration of such an option at the beginning of the project can allow in raising the valuation of the project, especially for capital intensive projects. These options

help in reducing the option of capital intensive to complete failure. According to Herder et al.(2011), while valuing this option, the decision-makers need to ask: “Are continuous operations always required? Can the resources be re-allocated to other innovative projects?”

Example in maritime: For the options to abandon or switch in a port context, the port authorities can choose the option to be a ‘spoke’ port instead of a ‘hub’ port (Taneja et al.,(2011). This article also mentions an example for the option to shut down temporarily by limiting the port authority to transhipment due to inadequate development of road and rail infrastructure in the hinterland.

- *Option to grow*
  This kind of option relates to the additional opportunities created due to the decision on the initial project. Damodaran(2000) claims that it is the initial project which allows the decision-maker to grow in the market and gives the advantage for further expansion. The option to grow according to Trigeorgis2005 can be viewed as a baseline capital outlay along with a call option on the future capital outlay. The option to grow can give the decision-maker strategic value as it allows for capitalising on future market growth prospects. This option varies from option to alter scale in a way that, the option pertains to valuing the growth opportunities which might be available due to the initial investments. Though the difference between the option to grow and the option to alter scale might seem negligible, the baseline assumption varies.

  Example in maritime : For the option to grow, Taneja et al.(2011) presents a fitting example. According to the authors, the port authority could design a multi-functional port in terms of underground storage of carbon dioxide and LNG container.

- *Option to alter scale*
  After the project decision has been, this option allows the decision-maker to adapt the project to the existing market development and competitor activities. The altering scale allows for both expansion and reduction of the scale of business based on market conditions. This option is especially popular when innovative products are introduced within the market. Option to expand can be understood by the analogy to “riding on the gains” and the option to contract can be understood by the analogy of “cutting loses” (Mittal,2004). According to Herder et al.(2011), while valuing this option, the decision-makers need to ask: “What is the minimum and the maximum scale of the project? Is it possible to develop a more flexible scale which makes it possible to extend or contract operation in the face of an uncertain?”

  Example in maritime: According to Taneja et al.(2011), an example for the option to alter scale in port projects could be to plan the port expansion in phases based on the response to demand.

3.2.2. Methodology for Real Options

According to Mun(2002), Peters(2016b) and Copeland and Antikarov(2001), the objective of modelling through a real options approach is to find an efficient solution for real decision problems which lets the decision-maker adapt based on the impacts of uncertainties and system-based complexities. To find this efficient solution, Peters(2016b) categorises real options into two broad categories of analytical and numerical approaches. If the solution is to be found using the mathematical methods of calculus, trigonometry and other techniques, it is called an analytical solution (also referred to as a closed-form solution). Real-time systems involve complexities which may not fit within the assumptions of sophisticated or higher-order mathematical situation, requiring a methodology which allows for calculating approximate solutions. These solutions are found through numerical approaches (Peters,2016b). The following are the approaches that are predominantly used to implement ROA.

Classical Approach

The classical approach can be summarised as a direct application of the Options Pricing Approach of Black and Scholes(1973) methodology to real assets. Black and Scholes(1973) methodology allows valuing European options through a risk-free interest with a no-arbitrage assumption. According to Myers and Brealey(1995), a no-arbitrage assumption involves that the asset is valued solely based on the value of the asset without considering alternative fluctuations in the market. For instance, a case of arbitrage involves when a stock is purchased in New York Stock Exchange and is then sold in London Stock Exchange for a higher price. This is called a situation of arbitrage. A no-arbitrage assumption involves the valuation of the asset without market-related price discrepancies.

This approach has been widely adopted to value financial options as it allows to consider the uncertainty of the future value of the underlying asset. Such an approach to consider probability distribution for the future value of the underlying asset solves the dilemma related to risk consideration in the discount rates.

Such an approach models European options. This implies that the option can be only exercised on the date of expiration. Decisions concerning real assets involve longer or changing periods of options validity. According to Brach(2003), the strict exercise rules and the assumption of European option within the classical approach severely limits the application of Black and Scholes(1973) approach for real assets. One of the other limiting factors of this construct stems from the consideration of only one uncertainty. Most real assets involve multiple sources of uncertainty which is required to be considered for robust decision making. In these cases Black and Scholes(1973) will be limited or prove erroneous. Additionally, this methodology is an analytical approach leading to a closed-form solution, which makes it difficult to mirror the real-time complexities. Although the equations involve six parameters that are to be calculated, the mathematical equations can become quite complicated when it is applied for calculating option values of real assets (Peters,2016b). The Black and Scholes(1973) is built on the assumption that a replicating portfolio can be created for the underlying asset. This assumption need not prove to hold in the cases of infrastructural assumptions, wherein the underlying asset is not traded. The Black and Scholes(1973) process assumes that the underlying process consists of no jumps or shocks in the variable. It is assumed to be a continuous-time process wherein the variance remains constant throughout the life of the option. Assuming constant volatility for real assets (especially infrastructures) might be unreasonable as the underlying state variables might vary throughout the project timeline. Port projects for long project timelines cannot be assumed with constant volatility. Some trends might highlight constant volatility but these trends also vary according to time and other interconnected factors (such as GDP, trade regulations etc). So constant volatility assumptions for longer time intervals will be limiting.

Binomial Options Pricing Model

This approach was formulated by the work of Cox et al.(1979). The decision problem is framed using a discrete stochastic process in form of a binomial tree which is further divided into intervals (also called nodes). This approach like the classical approach follows the approaches of replicating portfolio and no-arbitrage[1]. Additionally, the valuation formulas of Cox et al.(1979) assumes that, the valuation is taking place in a risk-neutral setting. This implies that the investors are indifferent between receiving a risk-free cash flow and a risky cash flow.

The binomial tree follows similar principles to that of a decision tree analysis wherein there is a backward induction approach. However, the differences stem from the use of risk-neutral probabilities which are associated with the branches of the tree. The future value of the underlying asset is determined by an upward or downward movement at each discrete step. The upward and downward is determined by the risk-neutral probabilities at each step of the tree. If an initial asset has a value of C then in the next period there a probability p that C will move upward and will now have a value C_u. There is also a probability of $1 - p$ that it might move downwards and then have a value of C_d. This is now possible for multiple periods and this is visualised in Figure 3.5.

The binomial tree provides the decision-maker to calculate the critical value to invest after which the option value starts losing its value (Brach,2003). The Cox et al.(1979) provides a transparent picture of the effect of time on the option value and allows to understand the behaviour of the selected uncertainty on the overall value of the project.

It is the concept of the replicating portfolio that makes the model by Cox et al.(1979) limited to investment projects wherein a traded twin security is available. The other limiting factor is the requirement that the risk and the uncertainties of the investment project should be similar to the traded twin security. In practice finding such twin security for a real asset (especially like ports) is complex. The future value of the real asset might result in more than two outcomes at a discrete-time node in the tree. At this moment, the construct of the binomial tree is a limiting factor. The works of Copeland and Antikarov(2001 considers multi-dimensional trees but the computational complexity increase as the multinomial tree progresses.

Contrary to Black and Scholes(1973), the Cox et al.(1979) provides a clear framework which is built on the foundation of discrete time intervals. The discrete-time intervals can be said to be of value for the decision-

[1]A no-arbitrage assumption involves that the asset is valued solely based on the value of the asset without considering alternative fluctuations in the market. For instance, a case of arbitrage involves when a stock is purchased in New York Stock Exchange and is then sold in London Stock Exchange for a higher price. This is called a situation of arbitrage. A no-arbitrage assumption involves the valuation of the asset without market-related price discrepancies.

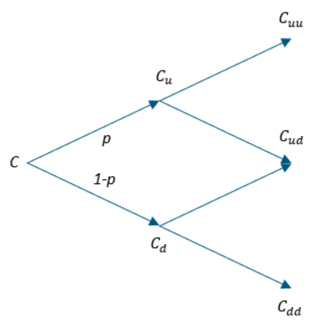


Figure 3.3: Depiction for Binomial Options Pricing Tree

maker as it allows for analysing the value of the options at different intervals before the time of expiration. Additionally, the method is intuitive in the way it calculates the jumps within the state variables and allows for calculating approximate solutions for valuations.

Monte-Carlo Simulations

The Monte Carlo approach is a simulation approach that allows for generating several paths for the future potential value of the asset. This is crucial considering that the crux of ROA is considering and using the underlying volatility. Monte Carlo simulations are generally applied in combination with a stochastic process (such as GBM or Mean Reversion Model (MRM)). The ability to consider random values within a distribution makes the Monte-Carlo approach a likely combination with the underlying stochastic process. Several path generations of the stochastic processes can help in assigning path dependency and determining the growth of uncertainty for the chosen uncertainty state variable (Baldwin et al.,2000) (Peters,2016b). This approach also shows significant flexibility in terms of consideration of uncertainties. Several uncertainties can be considered by combining the probability distributions of the underlying stochastic processes (Peters,2016b). One of the cons of a static DCF approach is the resultant single-point estimates of cash flows. The Monte-Carlo approach allows breaking that limitation by considering the inputs as a distribution and resulting in outputs with expected values. Besides the expected values, using Monte-Carlo for real options results in probability density curves and enough data points which can be used to calculate option values at various confidence intervals. Finally, this approach aids in creating a boundary curve that lets the decision-maker create a threshold value for the option. Unlike the approaches of Black and Scholes(1973) and Binomial Options Pricing, Monte Carlo simulations are efficient solutions in the cases of multidimensional problems. Monte Carlo simulations have been significantly used by de Neufville et al.(2005), Geltner and De Neufville(2018) and Copeland and Antikarov(2001) to calculate option values for real assets. It has also been observed that with the increasing complexity of the problem (in terms of the number of uncertainties, options consideration, option types), simulation approaches such as Monte-Carlo have gained momentum in ROA.

One of the cons of the Monte-Carlo approach is the computational complexity (especially for American options). Secondly, this approach is a forward-looking approach wherein the inputs and the underlying distributions are selected before the simulation. Unlike binomial options pricing which uses backward indication or dynamic programming, Monte-Carlo approaches are limited by the necessity to seal the assumptions before the analysis is conducted. the assumptions are required to be sealed to run the model. In cases of dynamic programming, these assumptions can be varied at each stage of the calculation. Unlike Black and Scholes(1973), Monte-Carlo Simulations in itself does not result in an option value, it is a methodology to calculate option value through the outputs from the simulation.

Market Asset Disclaimer Approach

The Market Asset Disclaimer (MAD) Approach originated from the work of Copeland and Antikarov(2001) which builds further on the foundation of Cox et al.(1979). The presence of twin security is often cited as a limitation for the application of ROA. The MAD presents an approach for real-life applications wherein it is impossible to find a replicating portfolio that is correlated with the outcomes of the project. This approach suggests that the twin portfolio is the baseline static DCF itself. Copeland and Antikarov(2001) make an argument that the perfectly correlated security for the project is the project.

The MAD approach is implemented by using the steps visualised in Figure 3.4. Copeland and Antikarov(2001) model the uncertainty using a random walk (GBM) which can be then combined into a single unit of uncertainty through Monte-Carlo simulations. Translating the valuation into an event tree involves assigning possible future values under potential and likely market scenarios. Assigning risk-neutral probabilities along with the addition of decision nodes transforms the event tree into a decision tree. The approach follows behaves as recombining trees which move in either upward or downward (similar to Cox et al.(1979)). Finally, through backward induction, the option value is calculated at each node which finally allows for calculating the project with flexibility.

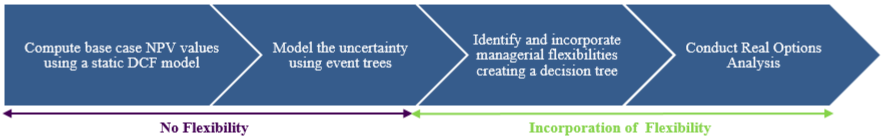


Figure 3.4: Market Asset Disclaimer Approach (*Source: Copeland and Antikarov(2001)*)

Although Copeland and Antikarov2001 present an implementation approach from a practitioner's perspective, there is limited discussion about the value of this approach over other implementation approaches. Additionally, the simplicity of assumptions within this approach is not validated by many case implementations (Peters,2016b). Borison(2003) casts doubt over the validity of GBM as a stochastic process irrespective of the underlying nature of the asset. There are also questions raised on the completeness of the MAD assumption in the cases of where a replicating portfolio can be made by market information.

Engineering approach or the Spreadsheet Approach

The spreadsheet approach is also known as the parking garage example is the resultant of de Neufville et al.(2005). This approach was implemented on Microsoft Excel making it easily adaptable for the practice consisting of a stochastic demand model and analysis of option values. de Neufville et al.(2005) used this approach to value flexible strategies for valuing a case of a multi-level parking garage.

de Neufville et al.(2005) provides a framework for evaluating investment strategies that involve large up-front CAPEX which face uncertainties resulting in impacts on the short-term and long-term gains from the asset. The investment must be calculated for the potential demand rather than the average demand. This methodology highlights that alternatives designed for flexibility result in greater monetary benefits than static alternatives. Expected-NPV is represented by the average value of NPV derived from the Monte Carlo simulation in the model.

Figure 3.5: Binomial Options Pricing Tree

The initial steps are similar to the MAD approach wherein the static NPV and forecasts are calculated. It is from the demand projections wherein the randomized or the stochastic component is initialised. The stochastic nature of the demand is done through Monte-Carlo simulations of an underlying probability distribution. The randomised values of demand are used for calculating NPV distributions. Different scenarios are created with the probability distributions of NPV. Based on the evaluation of these distributions the expected value of NPV is calculated along with the Value-at-risk for each option. This methodology presents the simplicity of being implemented on Microsoft excel and uses analysis which a practitioner might be used to. However, the assumption of a uniform probability distribution is said to be too simplistic (Peters,2016b). It is critiqued by Peters(2016b) that, this approach does not present appropriate reasoning for using a uniform probability distribution. Additionally, the computational complexity increases with the increase in the level of detail in the cash-flow calculations.

Takeaways from the broad approaches

Although being the first formal method to value European options, the approach by Black and Scholes(1973) is observed to be limiting in terms of the dynamics of infrastructural projects (Wang and De Neufville,2005). This is due to the consideration of replicating portfolios and continuous-time processes. The decisions for infrastructural development or expansion is made in discrete time intervals. Similar can be said for port infrastructural decision making, wherein the decision-maker will benefit from using the options at different time intervals. Modelling the options through discrete-time stages allows for replicating the active management style of a decision-maker.

Binomial Options pricing through lattices allows for considering discrete time intervals for option exercise. However, this approach is limited by its requirement for twin security matching the risk profile for the asset. Finding a traded asset matching the risk involved in the infrastructure will be monumental. Although Amram et al.(1998) consider a replicating portfolio while implementing RO, there are significant acknowledgements on the limitations of such an approach. According to Borison(2003), due to the limitations in replicating portfolio assumptions, the option values are prone to erroneous calculations and clumsy risk calculations. Therefore, the use of such an approach might be limiting for its application in infrastructural decision making.

Copeland and Antikarov(2001) provide a solution for approaching the limitations of replicating portfolio assumptions. The MAD approach is relevant for decision-makers who do cannot create twin security which mimics the risk profile of the project. Although Copeland and Antikarov(2001) present the added value of RO through the MAD approach, the authors do not address the added value of MAD approach over other approaches. Borison(2003) claims that, the simplistic approach of Copeland and Antikarov(2001) requires further validation to the employed stochastic processes and multinomial approaches. According to Wang and De Neufville(2005), the use of lattice approaches (especially within infrastructural systems) results in cumbersome calculations and assumptions to withhold the recombination property of the lattice. Monte-Carlo Simulations on the other hand is not limited to many assumptions as Black and Scholes(1973). Additionally, the issues with multi-dimensions and path dependence can be accounted for, by Monte-Carlo Simulations. However, Monte-Carlo simulations is a forward-looking technique unlike the backward induction methodology of binomial lattices. The forward-looking techniques is particularly a limiting factor as it induces static nature in the modelling process. The results of Monte-Carlo simulations do not directly result in actionable insights. Additional analysis is required to make sense of the results obtained through Monte-Carlo simulations. This is unlike the lattice approaches which is used in binomial options pricing and the MAD approach. Borison(2003) claims that Monte-Carlo simulations are prone to error due to the requirement of sound assumptions while defining the stochastic process. The engineering approach or the spreadsheet approach by de Neufville et al.(de Neufville et al.) is built on the premise to use the existing tools which are used by practitioner's to make real decisions. The combination of Monte-Carlo simulations and decision rules allows for considering many uncertainties and is claimed to result in a relatively easy implementation process. However, it has been observed that the assumptions seem too simplistic and opaque. Lack of validation on the stochastic process and the solution methodology can be said to be one of the limiting factors.

Copeland and Antikarov(2001) significantly herald the MAD approach over NPV by claiming, *"NPV systematically undervalues every investment opportunity". In 10 years, real options will replace NPV as a central paradigm for investments decisions"*. It has been 20 years since investment decisions in port infrastructural decision making are still dominated by traditional valuation techniques.

The ease of static DCF models over ROA should not be undermined. The traditional approach allows for convenient calculation with relatively lesser computational and mathematical complexity. Furthermore, it also allows for effective communication of results to the decision-maker.

3.2.3. Real Options for Infrastructural Systems

Within infrastructural applications, the implementation of ROA follows the baseline of approaches mention in subsection 3.2.2. However, there are significant variations in which the stochastic processes and the options analysis approach are varied. With this subsection, the implementation approaches are tabulated in Table 3.1 and are further explained for their mechanics. The tabulated list of articles focuses present ROA based on approaches presented in subsection 3.2.2. Therefore qualitative works on ROA and the notion of RO thinking for infrastructural projects were not considered. In the second half, the current approaches within port infrastructural applications are presented and discussed in detail.

Current ROA applications in infrastructures are focused on solving for three main insights, Firstly, it is about

[2] NA specifies Not Adequately mentioned

Table 3.1: Approaches for Real Options in Infrastructural Systems

Source	Infrastructure	Decision Problem	Uncertainty Parameters	Stochastic Process	Methodology	Discount Rate Assumption
De Neufville et al.(2008)	Transport (intelligent transport)	Option to grow	Net Payoffs	Random walk (GBM)	Lattice analysis through backward induction.	NA[2]
de Neufville et al.(2005)	Multi-level Parking Facilities	Option to alter scale	Future Demand	NA	Monte-Carlo Simulations	Risk-adjusted
Chiara et al.(2007)	Transport(BOT - Toll road)	Option to alter scale	Net Payoffs	Random walk (GBM)	Monte-Carlo Simulations	WACC
Morgado et al.(2011)	Transport (Airport)	Option to alter scale	Future Demand	Random walk (GBM)	Lattice analysis through backward induction.	Risk-adjusted
Lethanh and Adey(2016)	Transport (Railway)	Option	Deterioration of asset	Random walk (GBM)	Black and Scholes	Risk-free
Zhao et al.(2004)	Transport(highway)	Option to alter scale	Future demand, land price and highway service quality	Random walk (GBM)	Monte-Carlo Simulations - Least Square Method	Risk-adjusted
Collan and Savolainen(2020)	Buildings	Staged Market Entry	Construction Time, Cost and Lease Prices	Triangular Fuzzy Distribution	System Dynamic and Monte-Carlo	Risk-adjusted
Ho and Liu(2003)	A/E/C Firm's Perspective	Option to defer	Net Payoffs	Random walk (GBM)	Binomial Lattice by backward induction	NA
Oliveiraa et al.(2020)	Transport (Airport)	Option to grow	Future Demand	NA	Binomial Lattice by backward induction	WACC
Zhao and Tseng(2003)	Multi-level Parking Facilities	Option to alter scale	Future Demand	NA	Trinomial Lattice by Dynamic Programming	Risk-adjusted
van den Boomen et al.(2019)	Transport(Bridge)	Maintenance and Replacement	Construction Costs	Random walk (GBM)	Binomial Lattice by backward induction	Risk- neutral probability approach and risk-free discount rate
Cheah and Liu(2006)	Transport(Causeway)	Concession Guarantees	Traffic Volumes and Growth	Log-Normal Distributions	Monte-Carlo Simulations	Risk-adjusted (return on equity)
van den Boomen et al.(2020)	Transport(Bridge)	Maintenance and Replacement	Price uncertainty, ageing and structural failure	Random walk (GBM)	Binomial Lattice by backward induction	Risk-free
Balliauw et al.(2019b)	Transport(Port)	Option to expand	Demand Uncertainty	Random walk (GBM)	Dynamic Programming	NA
Balliauw(2020)	Transport(Port)	Option of timing	Demand Uncertainty	Random Walk(GBM)	Optimisation and Dynamic Programming	Risk-adjusted
Guthrie(2009a)	Real Estate	Option of timing and altering scale	Future Property Prices	Random walk (GBM)	Binomial Lattice	Risk-free
Zheng and Negenborn(2017)	Transport(Port)	Option to grow and timing	Demand Uncertainty	Random walk (GBM)	Least Squares Method - Monte Carlo Simulations	Risk-adjusted
Lagoudis et al.(2014)	Transport(Port)	Option to alter scale	Demand Uncertainty	Random walk (GBM)	Monte-Carlo Simulations	Risk-adjusted
Taneja et al.(2011)	Transport(Port)	Option to alter scale	Demand Uncertainty	Uniform Probability Distributions	Monte-Carlo Simulations	Risk-adjusted
Cardin et al.(2017b)	Nuclear Power Plants	Option	Electricity demand	Random walk (GBM)	Monte-Carlo Simulations , decision rules and optimisation	Cost of Capital
Cardin et al.(2017a)	Waste-To-Energy	Option to stage	Waste Volumes	Random walk (GBM)	Approximate Dynamic Programming	NA
Geltner and De Neufville(2018)	Buildings	Option of timing	Price uncertainty	Random walk (GBM)	Monte-Carlo Simulations	Risk-adjusted
Reyes et al.(2019)	Transport(Port)	Option to alter scale	Demand Uncertainty	Random walk (GBM)	Monte-Carlo Simulations	Risk-adjusted
Ashuri and Kashani(2011)	Buildings	Option to stage	Energy Price	NA	Binomial Lattice and Monte-Carlo Simulations	Cost of Capital
Novaes et al.(2012)	Transport(Port)	Option to alter scale	Demand Uncertainty	Random walk (GBM)	Dynamic Programming	Risk-free rate
Haehl and Spinler(2018)	Transport(Port)	Option to alter scale	Demand Uncertainty	Random walk (GBM)	Approximate Dynamic Programming	NA
Elvarsson et al.(2020)	Parking Garage	Option to stage	Demand Uncertainty	Random walk (GBM)	Monte-Carlo Simulations	NA
Martani et al.(2016)	Ground source heat pumps	Option to alter scale	Gas and Electricity prices, Demand and Coefficient of performance	NA	Monte-Carlo Simulations	NA

valuing flexibility for the intervention plans. Multi-stage interventions are said to have a value that a traditional valuation approach does not capture. According to Cardin et al.(2007), the value of flexibility can be calculated using the following equation:

$$V_{\text{Flexibility}} = MAX\left[0, NPV_{\text{Flex}} - NPV_{\text{Non-Flex}}\right] \tag{3.1}$$

Finally, ROA are used to calculate the option value for altering the scale of intervention and the timing of these interventions. Based on the modelled uncertainty, potential moments are calculated wherein the decision-maker can maximise the pay-offs associated with the underlying asset.

Projects with long lead times, irreversible investments and single point estimates benefits with the application of ROA as it allows for valuing a multitude of scenarios connected to the behaviour of the underlying stochastic parameter. The idea of ROA is consistent throughout the literature, but the methodology varies, the mechanics vary. Firstly, the methodology to assess the future behaviour of the uncertainties is described using a stochastic process. The choice of the underlying uncertainties is dependent upon their influence on the financial outcomes. Based on the select articles mentioned in Table 3.1, it has been observed that for infrastructural applications the common source of uncertainty is considered as demand uncertainty. This is especially the case of infrastructural applications for transport networks; for instance: Chiara et al.(2007), de Neufville et al.(2005), and Oliveiraa et al.(2020). 12 out of the 17 articles related to transportation infrastructure, mentioned in Table 3.1 use demand as a parameter of uncertainty. Transport infrastructure can be said to be built around a certain expectation of future demand. This future demand most significantly influences the baseline financial outcomes of the decision plans. According to the review paper of Machiels et al.(2021), the primary choice of demand uncertainty for ROA applications is connected to its ability in influencing the real financial success of transportation projects. Following demand uncertainty, it is the uncertainty in prices(construction, equipment and material costs) that is more significantly considered as the source of uncertainty. However few numbered articles such as Zhao et al.(2004), Collan and Savolainen(2020), Cheah and Liu(2006) and van den Boomen et al.(2020) use multiple sources of uncertainties. For instance, Zhao et al.(2004) used both demand and land price uncertainty to value the option expanding. The use of multiple uncertainties is said to increase the computational complexity and requires tight assumptions. Secondly, the choice of stochastic process to forecast the behaviour of the uncertainty is surprisingly constant. In the cases of articles wherein the mechanics of stochastic process was presented, it was observed that the use of random walk -GBM is prevalent. Within these articles, there is little attention given to the motivation for the choice of stochastic processes. Some articles are seen to mask this as probability distributions and do not provide enough mechanics to verify and validate their assumptions. There are articles such as that of Collan and Savolainen(Collan and Savolainen) who consider distributions such as triangular distributions and treat the pay-offs to be a fuzzy number.

Thirdly, within infrastructural applications, the most frequently employed methodologies involve either lattice (13/28) or Monte-Carlo simulations (15/28). It is only Lethanh and Adey(2016), where the classical approach is followed. Articles involving Monte-Carlo simulations are observed to use demand as a parameter of uncertainty and use specific decision rules to maximise the expected value of the project. Applications in Martani et al.(2016) and Zhao et al.(2004 can be understood as a probability simulation model which results in many probability distribution outcomes which are focused on providing the expected value of the project. Approaches employed by Elvarsson et al.(2020) involve the addition of objectives to interpret the results of Monte-Carlo Simulations. Based on decision rules and objectives, the optimal moments of investments and the magnitude of investments are calculated.

On the other hand, lattice approaches involving backward induction or dynamic programming communicates the optimal moments of intervention by linking the uncertainty parameter and net pay-offs. For instance, the works of Guthrie(2009a) and van den Boomen et al.(2019) work from the end of project timeline to the start of project timeline. Doing so results in communicative results of optimal timing based on various scenarios and also aids in developing boundary curves for investments.

Approaches of Cardin et al.(2017a) and Zhao et al.(2018) involve optimisation and simulation-based approaches which involve algorithms to solve for the objective of ROA implementation. These applications view ROA from an optimisation problem which is solved using multi-integer programming and solution algorithms. Such applications though limited are gaining prevalence due to their ability to solve complex problems such as multi-facility- multi-capacity problems with greater computational efficiency than the conventional Monte-Carlo or lattice approaches.

20 out of the 28 articles conclude their applications with the notion that ROA analysis allow value flexibility by staging strategies. These articles were focused on comparing the flexible strategies (in terms of multi-stage expansions) against the inflexible strategies. Other than valuing flexibility, articles such as Elvarsson et al.(2020) and Balliauw(2020) focused on identifying optimal moments of investments wherein a flexible strategy will generate maximum pay-offs. Although there is a difference in the methods and the underlying assumptions of the articles tabulated in Table 3.1, all of them considers uncertainty and advocates for adapting the decision making process through alternative strategies rather than the “Predict and Control” notion of a static DCF approach. The conclusions of the researchers indicate the necessity of identifying and using the uncertainty within the valuation model.

3.2.4. Approaches specific to Ports

There are primarily four articles that are prominently cited for its ROA application within port infrastructural decision making. The particulars of these articles are tabulated in Table 3.2.

Firstly, Taneja et al.(2011) presents a ROA framework for adaptive port planning, which is then implemented for the case of Port of Rotterdam. The central objective is to extend the economic life of the concerned sub-system within the port. The option valued was the flexibility in altering scale. The framework of Taneja et al.(2011) for valuing flexibility “in” infrastructure is visualised in Figure 3.6.

Taneja et al.(2011) applies the framework on two different sub-systems of the port: mooring dolphins and

Table 3.2: Approaches for Real Options in Port Infrastructural Systems

Source	Infrastructure	Decision Problem	Uncertainty Parameters	Stochastic Process	Methodology	Discount Rate Assumption
Taneja et al.(2011)	Transport(Port)	Option to alter scale	Demand Uncertainty	Uniform Probability Distributions	Monte-Carlo Simulations	Risk-adjusted
Reyes et al.(2019)	Transport(Port)	Option to alter scale	Demand Uncertainty	Random walk (GBM)	Monte-Carlo Simulations	Risk-adjusted
Balliauw(2020)	Transport(Port)	Option of timing	Demand Uncertainty	Random Walk(GBM)	Optimisation and Dynamic Programming	Risk-adjusted
Lagoudis et al.(2014)	Transport(Port)	Option to alter scale	Demand Uncertainty	Random walk (GBM)	Monte-Carlo Simulations	Risk-adjusted

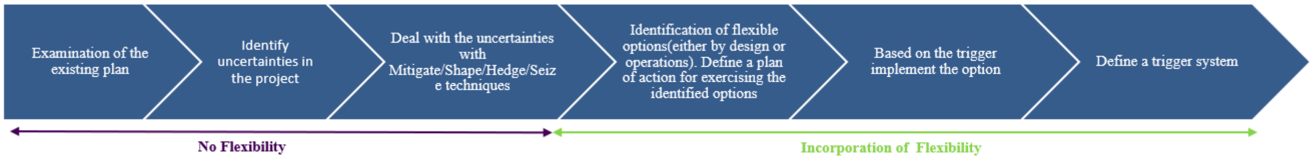


Figure 3.6: Adaptive Planning Approach using Real Options for Ports by Taneja et al.(2011)

quay walls. The considered parameter of uncertainties was growth in vessel sizes and demand. Monte-Carlo simulations were used to create a variety of futures which is then used to evaluate the flexible strategies.

A similar application to Taneja et al.(2011) is followed in Reyes et al.(2019). Reyes et al.(2019) uses the real options framework to adaptive planning and the implementation is done on a Caribbean port. The key difference in Reyes et al.(2019) application is the use of dynamic forecasting through a random walk process. Additionally, Reyes et al.(2019) focuses on the expansion of the container yard and the deepening of quay walls. These articles present the value of real options by comparing the monetized value for a flexible development against an inflexible expansion strategy. Taneja et al.(2011) concludes that flexibility might require additional capital outlay but such an approach but it is still “minor” when compared to the total costs. It is also claimed that this flexibility will allow for lengthening the economic lifetime of ports in comparison to inflexible strategies. It is the expected value of NPV which is used to evaluate the strategies which are obtained through cumulative probability distributions resulting from the Monte-Carlo analysis. Both these articles focus on valuing the option wherein flexibility can be devised “in” the infrastructure.

Secondly, it is the work of Lagoudis et al.(2014) who presents a two-fold framework to identify and assess flexible strategies for capacity expansions. This approach varies from that of Taneja et al.(2011) as it focuses on flexibility “on” infrastructure. This approach is visualised in Figure 3.7.

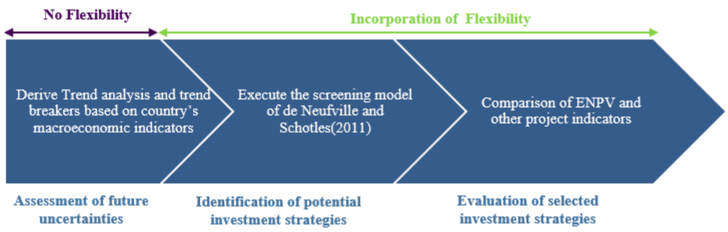


Figure 3.7: Two- step approach for Real Option in Ports by Lagoudis et al.(2014)

Lagoudis et al.(2014) proposes a framework for assessing flexible strategies for warehouse expansions in a port. The framework consists of two processes. The first one is a methodology to measure the system's capacity. This step allows in identifying the bottlenecks within the current system. While the second process involves evaluating the investment strategies through the methodology presented within de Neufville and Schotles(2011). Through this step, the necessary investment is evaluated to solve the bottlenecks. The process mechanics are explained in the following steps:

1. Phase 1: Assessment of future uncertainties

- Derive Trends analysis and the trend-breakers using the country's macro-economic indicators.
- Use Monte Carlo simulations in combination with random walk - GBM to generate future throughput volumes. This creates the foundation for the dynamic model.

2. Phase 2: Identification of potential investment strategies
Executed by using the screening model principles as presented by de Neufville and Schotles(2011). The screening model identified expansions that can aid in alleviating the current cause of congestion. The expansion strategies were focused on the objective of reducing future congestion.

3. Phase 3: Evaluation of these selected investment strategies.
Comparative analysis done using comparing the expected values of NPV and Earnings before Interest, Taxes, Depreciation, and Amortization (EBITDA)

Lagoudis et al.(2014) recommends that, the port expansions needs to be adapted to the potential demand rather than average future demand. This research significantly addresses the gap within maritime literature which pertains to flexible evaluation of port investments. Lagoudis et al.(2014) concludes that flexible alternatives need not present an additional value over inflexible alternatives at all times. This approach although addresses the gap of valuing option of altering the scale, it does not analyse the value of flexible strategies in detail. The analysis is limited to the comparison of Expected values of NPV and EBITDA. There is limited discussion on the effects of postponement of the investing and the influence of flexibility on each cash flow.

Thirdly it is the approach of Balliauw(2020) wherein focus was specifically maintained on timing options for port capacity expansions. The research uses GBM for forecasting the uncertainty state variable. The uncertainty chosen is demand and the volatility is kept to be constant. The investment cost considers economies of scale and with every sizing assumption, there is a subsequent penalty cost that has been added. It considers three ports of varying capacities based on dummy data and does not display the complexities of a real-time port. This is especially seen for the revenue calculation. In terms of the process mechanics, this approach uses dynamic programming for multi-stage capacity expansion following Dixit and Pindyck(1994) with additional optimisation for profits. The approach by Balliauw(2020) tests the boundaries of flexibility in terms of moments and size of exercising. This particularly interesting result is the time until which capacity expansion can be delayed. The results of this article focus on the relationship between the attractiveness of the investment against the time of exercise and the capacity of expansion. Finally, Balliauw(2020) sheds light on the effect the nature of the investor has to play in the case of flexible decision making. In the case of a public investor, it has been claimed that the investment is made sooner in the project timeline than in the case of a private investor. The cons of this approach are the validation of the underlying assumption, the approach and framework are limited due to its application in a practical case. The approach is tested on simulated data for a brownfield project. Additionally, the simulation of the framework involves concepts of optimisation involving opaque and complex mathematical consideration.

The fourth approach involves the application of ROA along with game theory to evaluate expansion strategies when two ports are competing against each other. Works of Balliauw et al.(2019a) and Balliauw et al.(2019a) focus on such applications. Such an application is considered to be out of scope for the current research as the focus is maintained on single facility - multi-stage expansion without the consideration of competing for port's strategies.

The above mentioned approaches involve numerical model implementation of ROA, applications such as Balliauw et al.(2019b) and Meersman(2005) deals with ROA on a more conceptual level by presenting arguments for ROA and the methodologies which can be used to structure a ROA model for capacity expansions.

3.2.5. Conclusion of Theoretical Background

The current wealth of approach although present many alternatives to real options. All the applications present the benefit of staging or varying time in the valuation model using a stochastic process. The baseline approaches although consisting of specific disadvantages allow for flexibility to adapt the model assumptions based on the real-time complexity of the field of implementation. In the case of applications in infrastructural applications, the objective of ROA is to evaluate flexible strategies by maximising the expected pay-offs. However, it can be argued that such an approach might be uni-dimensional. The decision-maker might be interested to understand the comparison of different position(s) of investment by varying time of exercise and magnitude.

Observations in current applications

It is the uncertainty in demand which is used in a significant number of applications. From Table 3.3 it can be gathered that it is the uncertainty in demand which is significantly used for ROA. Uncertainty in technological developments and price(construction, equipment and material costs) are observed to be given lesser significance. This is especially the case of ROA implementation for port infrastructural applications. In Table 3.4 summarises the approaches for 28 articles which focused on the ROA implementation for infrastructural decision making. Although the focus of these articles was on valuing the concern option, all the articles strongly emphasise the requirements of assessment and consideration of uncertainty during the decision making. Although there are many implementations within infrastructural systems, the limited number of articles involve real-life case studies for which decisions are being made. The practical relevance of these methods is impeded due to its evaluation of results. These applications do not tailor the applications according to the case. Rather tailor the case according to the method.

Table 3.3: Summary of uncertainties considered for Real Options applications in infrastructural decision making

Uncertainty	**Frequency**			**Total Frequency**
	Transport	Buildings	Others	
Market related				
Demand	12	4	2	18
Price, Tariffs and Costs	2	6	-	8
Payoffs	2	-	1	3
Time	-	1	-	1
Asset and infrastructure condition related				
Deterioration of the asset	1	-	-	1
Highway Service Quality	1		-	1
Ageing and Structural failure	-	1	-	1
Coefficient of Performance	-	1	-	1

Table 3.4: Summary of approaches considered for Real Options applications in infrastructural decision making

Methodology	**Frequency**			**Total Frequency**
	Transport	Buildings	Others	
Lattice Analysis through backward induction/dynamic programming	7	4	2	13
Monte Carlo Simulations	8	6	1	15
Classical Approach	1	0	0	1

Takeaways from approaches which will be utilized in the conceptual framework

The approaches specific to the ports presented by Taneja et al.(2011), Lagoudis et al.(2014) and Balliauw(2020 will be further utilized for defining the conceptual framework in chapter 5. Three out of these approaches use Monte-Carlo simulations as a methodology to implement ROA. Additionally, the significance and frequency of the use of Monte- Carlo simulations has also been observed in the current literature. This can be attributed to its balanced approach in simplicity and theoretically grounded analysis. The methods to identify RO has been mentioned in detail in Taneja et al.(2011). This part of the framework will be further used in the conceptual framework to identify options in a project. The complete framework provided by Taneja et al.(2011) lacks context in the current scope of research. The article explores flexibility “in” ports, while the research is focused on flexibility “on” ports. The methodology to analyse options trade-offs has been described in detail by Balliauw(2020. Such an approach for options analysis will be utilized in the conceptual framework. Finally, the approach by Lagoudis et al.(2014) utilizes Monte-Carlo simulations for ROA for a real-time case in a south-east Asian port. The nuances of the assumptions will be used in the framework to ensure the designed framework has verified assumptions that apply to real-time cases. Additionally from a broader infrastructural application context, the decision rules concept for deriving the critical moments of expansion investment will be utilized from Cardin et al.(2017a). To calculate the value of flexibility is calculated using the approach of

Cardin et al.(2007).

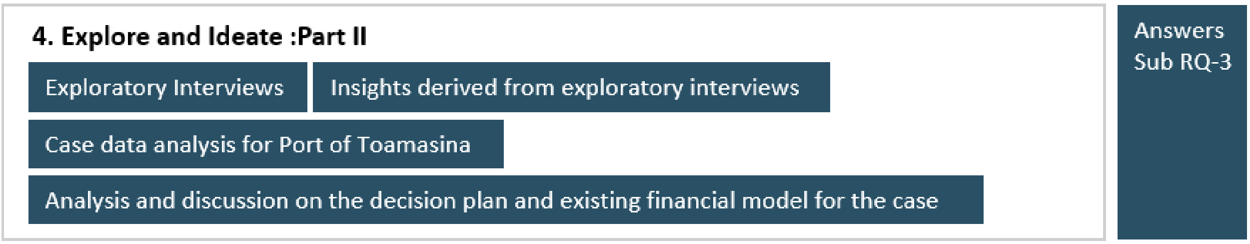
Approaches by Black and Scholes(1973) are not considered further in the design of the conceptual framework. This is due to the consideration of replicating portfolios and continuous-time processes which lacks practical relevance. Approaches such as the classical approach and lattice approach involve approaches such as risk-neutral pricing assumptions and consideration of risk-free interest rates. This can prove to be theoretically complex and difficult to validate for infrastructural assets. The MAD approach by Copeland and Antikarov(2001) is not considered while devising the conceptual framework as the simplistic assumptions on replicating portfolio approach has not been validated for infrastructural applications.

For ROA to be included within the decision-making process it is required the methodological choices are to be implemented and evaluated using real-time case values. The relevance of ROA as it is seems to have been theoretically proven. However, it is the practical relevance of which a gap is observed through this desk research. There is a requirement of developing industry-specific approaches rather than re-implementing the same techniques across all fields of implementation. There is one underlying objective that is repeated in all the approaches which are that of value creation. However, the underlying assumptions vary concerning the kind of uncertainty, approach used, the dimensionality of the solution, solution type, source of data, discount rate, probability, portfolio selection. The second gap observed through the desk research is the lack of application-specific implementation processes. There is a requirement to connect the approaches with the complexity of the case of implementation.

4

Explore and Ideate Phase - Part II

Trust, but verify.
— Russian Proverb



This chapter forms the second phase of the Explore and Ideate phase. The perspectives of the practitioners on the nature of the decision making, port planning and characteristics of port investments are presented in the first half of the chapter. In the second half of the chapter, the particulars of the case study of the African Port has been explained. The assumptions and the results of the financial valuation model for the case study are explained and analysed. The takeaways from the exploratory interviews are as follows:

1. Sources of uncertainty that influences the financial viability of the port development or expansion plan.
2. Current list of protocols for the consideration of uncertainty.
3. Characteristics of port investments and the decision-making process.

The takeaways from the case data exploration are as follows:

1. Background and the objectives for the expansion decision.
2. Expansion plan for the port.
3. Analysis of forecasts, cash flows and project indicators.

Through the takeaways from the exploratory the following sub research question has been answered:

- **Sub RQ-3**: What is the practitioner's perspective on the parameters of uncertainty and financial valuation of port infrastructural decision making?

The takeaways from the exploratory interviews are further considered while devising the ROA conceptual framework in chapter 5. Additionally, these takeaways have also been utilised in the discussion part of chapter 7. The takeaways from the case data exploration are significantly utilised while operationalising the conceptual framework into a numerical model. Moreover, the analysis of the current case data has been utilised in comparative analysis (chapter 6) and discussion section (chapter 7) of the report.

4.1. Exploratory Interviews

This section sets the context for the larger part of the research by providing insights of industry practitioners on the matters of risk and uncertainty within port infrastructural projects. Exploratory Interviews were conducted to understand the nature of port investments, port planning and the decision-making process. Apart from setting the context for further research, the results of the exploratory interviews will contribute to the knowledge pool of uncertainty factors within decision-making for port assets.

The exploratory interviews were intended to be carried out as a conversation between industry experts (one at a time) and the researcher. The knowledge of the interviewed experts allowed for understanding the dynamics of the decision-making process involved within port assets which confound their clients (the decision-makers). Based on their working knowledge, the key factors which induce volatility within such infrastructural decision making is explored and categorized. Moreover, the exploratory interviews allowed for a detailed understanding of other issues that the experts felt relevant to the research theme. Finally, the possibility to ask follow up questions allowed for connecting real-world instances with theoretical questions. The results derived from these interviews were qualitative and analyzed under the themes of port infrastructural decision making, port investments and port planning.

4.1.1. Approach

The exploratory nature of the interviews required to capture the perspective(s) and knowledge of experts who were involved in projects wherein the decision was concerned about the development or planning or expansion of a port asset. A semi-structured form of interviews was adopted to fulfil the objective. According to Bryman(2016), a semi-structured form of interviews allows for a context wherein the interviewer can ask a series of questions (similar to a closed question of that of structured interviews). Additionally, it also gives the interviewer the flexibility to ask follow up questions.

The interviews were conducted online and lasted for 45 – 60 minutes each for the interviews. To avoid singular opinions on port infrastructural decision making, an expert sampling methodology was employed. Such a sampling methodology involved selecting professionals from different backgrounds or sub-businesses units within Royal HaskoningDHV. A total of 8 professionals from the Maritime and Aviation unit of Royal HaskoningDHV were interviewed. The details of these professionals are tabulated in Table 4.1. The interviewees were provided with a brief background of the research objective and problem definition. Additionally, a framework of open-ended questions was provided before the interview. Both of these documents allowed for guiding the session and ensuring the relevance of the answers to the broader research theme.

Table 4.1: Details of the Interviewees

Code	Role	Group
MA_EO_D	Director	Maritime & Aviation - Economics & Operations
MA_EO_AD	Associate Director	Maritime & Aviation - Economics & Operations
MA_EO_IA	Senior Investment Advisor	Maritime & Aviation - Economics & Operations
MA_PM	Project Manager and Port Consultant	Maritime &Aviation
MA_D	Director	Maritime & Aviation
MA_MA	Manager Auditor	Maritime & Aviation
MA_PC	Port Consultant	Maritime & Aviation
MA_PE	Project Engineer	Maritime & Aviation

4.1.2. Key Observations

According to Taneja et al.(2010), port expansions comes with the complexity of adaptation to developments triggered by the market. Within this volatile environment, there is a dilemma to invest in developments and expansions with a long payback time for staying competitive in the region.Taneja et al.(2010) in her article presents other uncertainty factors such as future cargo flow, investment costs, project lifetime, raw material and product prices, interest and exchange rates and tax/regulatory policies affect the future cash flows within port investments. The additional sources of uncertainty in the decision for a port development stem from the decisions taken by other regional and international logistics actor, technological, regulatory and environmental trends (Meersman,2005). Throughout the interviews, these sources of uncertainty were mentioned by

Meersman(2005) and Taneja et al.(2010) were mentioned multiple times.

- *Characteristics of Port investments*
  As found in the literature Balliauw et al.(2019b) and Meersman(2005), the interviewees too mentioned investments within port infrastructures to involve high risk and high uncertainty. It was mentioned as risky, as it involves huge upfront capital expenditures and a slow payback time. However, brownfields projects were claimed to involve lesser risks in terms of capital expenditures. This was due to the greater availability of information that can help in anticipating future outcomes. The uncertainty within the initial or feasibility stages was said to be due to the high-level view taken on various aspects of the infrastructure. This view results in many assumptions which are not completely validated by real-time data. Based on the background of the interviewees, their definition of port investments and planning varied. For an engineer, it was the capacity and structural requirements. On the other hand, for a financial consultant, it was the financial feasibility and the business case. Even though their perspective varied, they all agreed that it is the market forecasts has a significant influence on the financial viability of the project.

- *Complexity within port investments*
  Port investments were said to be volatile due to the influence of exogenous (market-related) and endogenous (institutional) factors. According to one of the interviewees, the nature of work during the feasibility and pre-feasibility stages involves a high-level perspective which involves using many assumptions and benchmark values. These were remarked as the reasons for making the calculations complex. Moreover, the interviewee maintained that, the process of planning a port is dynamic, wherein the assumptions change and reality (site conditions) might be different than anticipated. This dynamic nature adds to the complexity of ascertaining an accurate estimate. "High-level perspective during the initial phases makes it difficult for obtaining accuracy within the calculations", said one of the interviewees.

- *Objective(s) of Planning a Port*
  The objective of a client to undertake a greenfield and brownfield project involves capturing a greater share of the market. In the case of a public commissioner, the objective also involves the country's infrastructure development initiatives. Expansion of a port is also instigated to stay competitive in terms of capacity and technological automation against other ports in the region. Finally, it could be to obtain greater returns or improving the financial performance, for which expansion is ideated.

- *Decision Making*
  Port development or expansion projects was said to involve a long lead time and requires a lot of analysis to lead from feasibility to construction stage. The process of planning a port was said to follow the cycle: Market forecast –> Shipping and Cargo forecast –> Size of infrastructure –> Structural requirements –> Shipping line requirements –> Broader logistics chain requirements –> Costs Calculation –> Financial Valuation. This cycle was said to take place in a socio-technical environment that consists of many stakeholders (private, public and international financing bodies). In most cases, the interviewees claimed this cycle is iterative. For instance, if a design alternative is not financially viable, the market focus is discussed and adapted. Within pre-feasibility stages, the clients are said to use outcomes of the financial model as a way to judge the potential of the project and make a go/no go decision. According to 3 out of the 8 interviewees, financial models are also used to confirm and re-affirm the client's analysis.

  Two of the eight interviewees mentioned that the underlying assumptions of the master plans and the financial model are prone to changes as the stages progress. The consultants mentioned that the changes in assumptions due to long planning, designing and decision process impacts the market forecasts, capital expenditures, operational expenditures, environmental and social issues. Firstly, the market forecasts were said to change as the decision process keeps progressing. The changes in the competitive landscape, the ambition of the client changes and additional analysis contributes to the changes in the figures of the market forecasts. Secondly, CAPEX was said to changes due to the deviation between the assumed cost of construction processes and the real costs. The real prices might have been budgeted in greater/lower figures within the financial model. Additionally, after the detailed design of the port, the construction materials or the processes might change based on their relevance, which again can induce changes in the calculations of CAPEX. Thirdly one of the interviewees mentioned the assumptions on OPEX are said to change due to the sheer vastness of the system of a port asset. The maintainability and serviceability requirements of sub-systems change based on market forecasts and the existing operational equipment. Finally, one of the interviewees also mentioned that the position on environmental and social issues might change as the project progresses. According to the same interviewee, Stakeholder behaviour concerning this matter varies as the decision process progresses.

- *Project evaluation*

  All the interviewees mentioned that all large infrastructural projects of the scale of ports are evaluated for their investments using a financial and a Cost Benefit Analysis (CBA) model. The financial analysis is derived from a DCF model, which considers the project cash flows for the given timeline. During the stages of the feasibility stage, 6 out of the 8 interviewees mentioned that, the parameters considered from the financial analysis involve NPV, IRR, return on investment and EBITDA. Through the interviews, it was understood that it is the public commissioner who gives greater importance to economic and social benefits. The CBA or the Societal - CBA model is used as a parameter of decision making by these public commissioners. 6 out of 8 interviewees maintained that CBA models are at times manipulated for supporting the investment decision. For instance, the private party will push the CBA model in case of low financial viability. On the other hand, the public actors especially, politicians are said to use societal benefits to serve their agenda of infrastructural investments.

  Regardless of a public or private party, evaluating the investments through the financial model is a major trend that is seen in clients. The objective of the client is to find a reasonable investment that allows their port services to be competitive and have an adequate return on investment which they can use to validate their investment.

- *Uncertainties within port planning*

  One of the interviewees remarked, *"The job of a port planner comes with working with lack of information and uncertainty"*. Port planning according to the interviewees was said to involve uncertainty stemming from the market, unit prices, cash flow calculations and the client's ambitions. The market is dictated due to volatility in the competitive landscape, vessel sizes, shipping lines and cargo type. According to the interviewee, during the feasibility stages predicting the long-term future for each of this sub-item is difficult. Therefore, the indicative market forecast becomes one of the biggest sources of uncertainty which also deeply influences the financial viability of the investment. Secondly, 5 out of the 8 interviewees maintained that the uncertainty within the unit price and the tariffs are dictated by the competitive landscape and existing regulations. For instance, the client cannot set lower tariff prices (in the anticipation of gaining more share of the market), as it will hurt the revenue cash flow streams. On the other hand, setting higher prices will result in gaining more share of the market. Thirdly, according to 4 out of the 8 interviewees, the CAPEX for the infrastructure creates uncertainty within the port planning and investments. The volatility within market prices of the construction materials and equipment was said to influence the capital requirements for the planned infrastructure. The future price developments of the materials and the construction process were said to induce uncertainty within CAPEX. The uncertainty of completion under the said costs and time was also said to make the investment decision risky.

  Generally, during the pre-feasibility or feasibility stages, OPEX was said to be calculated as a set percentage or use benchmark values for calculation. These percentage-based assumptions or benchmark values might change based on real-time values within the operation phase. The uncertainty in OPEX was said to be amplified due to the variable operational expenditures. The lack of data on such matters along with a lack of understanding of the interaction between maintenance expenditures and growing throughput volumes makes OPEX volatile. Lack of information and data on the objectives, site conditions, equipment costs and health adds was said to the uncertainty. This lack of information makes it difficult for considering such factors within the financial models. One of the interviewees quoted, *"The uncertainty starts from the initial meeting with the client. Most of the times, the clients are not sure of their needs and requirements"*. In these cases, the client has an objective but not a clear vision as to the feasibility of the alternative. Some interviewees mentioned that the ongoing efforts on automation and the smart port concept has not yet become completely sophisticated and reliable. Developments in the future within this space is remarked to be uncertain and can lead to changes in competitive or stakeholder behaviour.

  Table 4.2, lists the sources of uncertainty that were derived from the interviews. The list is tabulated against the number of interviewees mentioning it. These sources of uncertainty affect the port planning process by creating volatility in the financial outcome. To reduce the volatility through gaining more information, does not help in reducing the impacts of uncertainty, said one of the consultants. The mentioned sources of uncertainty is a result of the inability to measure the future outcome based on present information. The development of these factors in the future is said to create volatility within the valuation model which then influences the decision-making process.

Table 4.2: Sources of uncertainty

Uncertainty	Further Classification	Frequency (max. 8)
Market related	Competitive Landscape	4
	Vessel Sizes	3
	Shipping Lines	2
	Cargo Type	4
	Demand and traffic Forecasts	8
Unit Prices	Tariffs	5
Cash Flow Calculations	OPEX	5
	CAPEX	4
	Revenues	6
Instituitional	Political	2
	Government regulations and policy	1
	Environmental and Social Compliance	1
	Lack of information or data	4
Technological	Automation - Smart Ports	5

- *Managing uncertainty*

During the port planning process (especially during the feasibility stages), the client is interested to know what are the potential uncertainties which can create volatility in the financial and design outcomes. According to two interviewees, the client wants to understand the best and worst outcomes. According to 5 interviewees, the consultant's focus is on identifying possible sources of uncertainty. It is remarked by them that, the clients are not interested to understand the analysis or the calculations for the likelihood of occurrence. “for the client, it is to understand the financial viability of the alternative”. One of the consultants mentioned that the next step after identifying the sources of uncertainty is to add appropriate legal clauses and share the risks amongst the involved parties. One of the consultants mentioned that within the feasibility or ideation stages a risk and opportunity matrix is also developed. This allows for considering the upside of the risk and result in opportunities. The identification of opportunities allows for negotiations to convincing the other stakeholders about the potential of the projects.

The financial consultants within the interviewee pool conduct scenario analysis (wherein the possibilities of future are analyzed) and then sensitivity analysis is carried out. In some cases, expert judgment is also carried out on both the inputs and outputs of the financial model. The current consultants both technical and financial consultants within the company are knowledgeable on the extreme scenarios which allow for models which are sensitive to uncertainty.

Additionally, the consultants use bounds or bandwidth on the input values for considering uncertainty. Other calculation-intensive methods of the likes of Monte-Carlo analysis and probabilistic based models are developed based on relevance to the case. An additional effort for considering price-related uncertainties is to use contingency percentages. In some cases, the sources of uncertainty are considered qualitatively wherein the consultant provides a set of issues that could act as a source of uncertainty. This set of issues are expected to serve as a caution for the client. One of the consultants mentioned their methodology to consider uncertainty is to think and analyze with pessimism. “I am wired to have a sceptical perspective at the pre-feasibility stage. I look at everything that goes wrong and seldom focus on the optimistic scenario.

One of the consultants mentioned that some clients who are experienced within the port sectors focus on modular expansions wherein the expansion decisions are broken down into several smaller stages. The expansion is contingent upon the real-time performance of the previous expansion. This level of uncertainty consideration was remarked to be dependent upon the budget and client's requirements.

4.1.3. Implications

Many interviewees reiterated that port planning is a continuous process and involves many iterations until the final decision is made. Port investments were particularly said to be complex because it forms a node in the broader logistics chain. This involves many stakeholders with a variety of objectives which adds to the list of uncertainty mentioned within Table 4.2.

The use of DCF analysis was seen to be prevalent amongst the consultants, due to its ease of reporting outcomes and structured computations. Additionally, the client seems to be used to the outcomes of DCF. In some cases, the consultants need to also coach the clients on the results and analysis obtained from the DCF valuation model. Due to these reasons, the consultants prefer the tested and tried approach of a DCF model. However, all the consultants realised the shortcomings of a static DCF model involving the characteristics of single-point estimates and the lack of consideration of volatility/shocks by itself. The consultants use scenario analysis and sensitivity analysis as an add-on to the outcomes of the DCF model. Although scenario analysis allows one to understand the different outcomes of the project, it does not communicate the likelihood as a probabilistic analysis might. Broadly, the scenario analysis still assumes the variable to have a linear relationship with growth (albeit at different percentages)[1]. This assumption limits the consideration of volatility/shocks for the underlying variable.

It was learnt that all the consultants in the interviewee list, advise on a phasing strategy (both for greenfield and brownfield projects). According to their answers, breaking the projects into several smaller phases is one of the ways to reduce uncertainty. This reasoning involves the elements of options thinking. However, this concept of breaking the project into smaller sub-components is reflected within the financial model in a limited fashion. Probabilistic decision rules for capacity-based decision are limited and was claimed to be dependent upon the client's needs, budget and level of sophistication demanded. At the crux of their advice, adapting the planned capacity to the market by gradual scaling is beneficial. Although the consultants use a staging or scaling methodology, the current practice is still limited in terms of adaptable designs wherein a different direction can be taken after the alternative has been already chosen. Taking a different direction implies reworking the financial model and the design/layout of the port.

To build adaptive models the consultants mentioned that, there is a requirement of historical data, availability of budget and time. During the initial stages, the client checks for feasibility and wants to understand the position of the investment. At this moment, the adaptability or flexibility of the alternative is not a major concern. One of the interviewees remarked that stochastic consideration of cost data and market forecast can allow for displaying flexibility in the port planning process too. The stochastic financial model will allow for interaction between the design and the costs/revenues attached to the underlying plan.

4.1.4. Conclusion of Exploratory Interviews

Through the interviews, it can be claimed that a client is looking forward to understanding the potential of the development of the port in terms of its financial and design viability. The focus points are to comprehend the associated risks of the investments and understand the exposure to the best/worst cases. In some cases, the client is looking forward to an analysis through which they can validate their analysis and ambitions. Moreover, the analysis from the financial models is also used to find the leeway for negotiation which the client can further use against other stakeholders.

Port as a node in the greater logistics chain, is a strategic infrastructure that is prone to dynamic complexity. Planning for a port is an iterative process due to the developments within and outside the project environment. The financial outcomes of the project change as the project progresses. It was understood that a black box model which considers all project-related uncertainties is difficult to construct. However, smaller efforts of considering uncertainty through scaled expansions, active management, scenario analysis and stakeholder engagement help in reducing the volatility.

The interviewees were asked for highlighting the obstacles to implementing a flexible plan through a stochastic valuation model which considers the volatility of the chosen parameters. Firstly, planning for a flexible decision model adds to the complexity of both a knowledge and presentation standpoint. DCF was said to be a methodology that is tried and tested. The existing practice based on deterministic DCF evaluations has seen port operators surviving the shocks and the volatility. *"Yes, they might have faced losses, but they manage to hang on with a deterministic strategy"*, said one of the interviewees. Additionally, it was also inferred that forecasts cannot be taken for granted and considering many scenarios is also not feasible. It must be noted that each project for the consultants come with a set of deadlines, a budget and an associated

[1] However based on the use case and the sophistication of the model, it can consider dynamic growth percentages.

available team. Considering all the scenarios comprehensively is a challenge to the challenges the consultant is subjected to.

When RO thinking and methodology was presented to the consultants, the following questions arose: *"What is the level of sophistication required? Where to get the data from? How can the quality of data be assured or validated? What is the quantity (years) of data required?"*. They mentioned the sophistication of analysis directly depends upon the demands and experience of the client with investing within the port infrastructure. There is hesitation within the clients of the computational difficulty, data requirements, implementation hiccups and inexperience with such stochastic methodologies. Finally, there were questions about whether such a methodology will be understood and appreciated by the client.

The sources of uncertainty extracted from the interviews bears similarity with the sources of uncertainty mentioned by Taneja et al.(2012), Balliauw et al.(2019b), Meersman(2005) and Lagoudis et al.(2014. However, through the interviews, many of these sources were validated and an explanation of these sources was obtained. Additionally, it also addressed the complexities of port planning and decision making which was limited in these cited papers.

4.2. Case Data Exploration

Within this section, the particulars of the chosen case study are explained, analysed and discussed. This section uses the plans, propositions, claims and outputs made within Japan International Cooperation Agency(2015b), Japan International Cooperation Agency(2009) and HaskoningDHV(2020) as background materials. Articles from the Japanese International Cooperation Agency are used as they are providing a loan to the port authorities and the project plan package has also been authored by them. subsection 4.2.1, sets the context for the case study of the African Port. Following this, subsection 4.2.2, describes the assumptions, data and results observed within the financial model and the case documents. Finally, the case results and assumptions are critically analysed within subsection 4.2.3.

Royal HaskoningDHV was asked to structure a financial model which will help the port authority to negotiate a new concession agreement for the period 2025 - 2035 (HaskoningDHV,2020) to analyse the cash flows associated with the expansion and operation of the port during the period 2020-2050. The model considers the planned port infrastructural investments for the capacity expansion between 2020 - 2027. The financial model for the case involves cash-flow calculations regarding the business case of the terminal operator and the port authority which are associated with the container handling activities at the port. The model utilises currently available data regarding the planned investments, container throughput scenarios and annual reports.

- **Objective** : The utilisation of the case of African Port will aid in addressing the evaluation and methodological gap. Furthermore, the results will contribute to the existing knowledge pool. The evidence of the evaluation gap is shown by limited consideration of real-time data within existing RO models within the (explained within subsection 1.2.4). Additionally, the use of a case - study will aid in developing clarity and check for feasibility of methods for applying ROA within port infrastructural investments. The financial model developed by Royal HaskoningDHV for the case will act as the baseline model which will allow for a comparative analysis[2].

- **Motivation and Relevance**: The motivation for choosing the African Port as a relevant case for the current scope of research is as follows:

  – The current expansion decision for the Port Authority is based on an expectation of growth forecasted volumes and an increase in vessel sizes. The port expansion plan is subjected to a long continual development of 8 years requiring a capital expenditure of 350 million EUR. The decision-maker has to commit to a large irreversible investment, which will start generating payoff(s) several years after the capital investment has been commenced. These payoff(s) are dependent on the expected forecasted volumes. The potential of the projected forecasted volumes eventuating lies in an expectation that can go either way. The realisation of the anticipated forecast volumes contributes to the uncertainty. There is a possibility that the realised volumes are higher than the anticipated forecasted volumes or either way. The variation between the realised and anticipated forecast volumes induces uncertainty in demand. The uncertainty in the projected demand volumes makes the existing investments for the port expansions to be risky[3]

[2]Such a comparative analysis will allow for scrutinizing the theory of RO under the backdrop of the practical relevant case. Therefore, the use of the case study allows in fulfilling the design and the evaluation requirement of the research

[3]Variation in the demand will lead to variation in the expected payoff(s). Therefore, making the existing investment decision to be risky

- The existing expansion decision can be said to heavily relied upon the uncertainty surrounding the throughput volumes. The availability of historical Twenty-foot Equivalent Unit (TEU) volumes for African Port, allows for quantifying and forecasting the demand variable. Therefore, the presence of historical volumes and the influence of the demand uncertainty on cash-flows presents the second reason for choosing the case-study[4].
- Geltner and De Neufville(2018), Nembhard and Aktan(2009) and Copeland and Antikarov(2001), mention the requirement of a financial model as a necessity. The presence of a financial model fundamentally implies that the decision requires justification Otherwise, the absence of a financial model means that the active management of the project has been already decided without any requirements for a cash-flow modelling exercise. The current case consists of an elaborate financial model aimed at calculating the cash flow and facilitate the required decisions.
- The case - study involves a static - expansion plan which obligates the decision-maker to commit to a hardcoded timeline of investments. Through the implementation of ROA for the chosen study, actionable insights on flexible expansion plans and the benefits of options thinking can be contrasted against the static expansion plan. These expansion options can be said to pose the questions for potential optimal time(s) of investment and potential optimal magnitude(s) of expansion which is relevant to the implementation of ROA within port infrastructural context. Therefore, the ability to formulate and exercise expansion options by the decision-maker makes this case-study to be a prime application option.
- Expansion opportunities are said to become a real option only if the option is exclusive to the decision-maker (Damodaran,2012). Within the current case study, the decision-maker has the absolute rights to expand the existing port project. Therefore, the chosen case study meets the exclusivity criterion.

• **Scope**: Within the scope of the current research, the decision-making process and the business case for the port authority is considered. Such a scope makes, the *to be designed* numerical model consider the inputs relevant to the port authority. The focus and the scope of the thesis lie to model the port expansion problem through a RO approach. This involves the identification of expansion options and calculating the optimal moment of time and magnitude of investment(s) through the methods of ROA. Due to this nature of focus, the decision problem of the negotiation of a new concession agreement for 2025 - 2035 is said to lie outside the scope of the research[5].

4.2.1. Port Case Background

The case study port is situated in the south eastern zone of Africa. The existing port handled 2.4 Million tonnes of cargo in the year 2007. This handling capacity indicates that the port handled 71% of the total cargo and 91% of the international cargo for the year 2007 (Japan International Cooperation Agency,2015b). Further to this, the port is seen to handle more than 80% of all trade traffic (Japan International Cooperation Agency,2015b). After a period of political neglect and the economic stagnation following the 2009-2013 political crisis, the current political climate is set to recognise and commit to modernise transportation infrastructure to improve its economic competitiveness and establish itself as a key player in the region (Japan International Cooperation Agency,2015b) (Japan International Cooperation Agency,2009).

The historical trend of the GDP of the country is held as a symbol to project the future growth potential of the country. Figure 4.1, shows the growth/decline in GDP of the country from 2000-2019. From Figure 4.1, it can be inferred that after the economic downfall starting from 2009, there has been a decline of 3% during the period of 2009 - 2012. However, post this crisis, GDP is on recovery and shows an increase of 2.6 % for 2011 - 2015. And more positively the GDP growth reaches 4.2% for the period 2011-2016. The government of the country puts this positive increase in GDP in perspective and expects the trend to continue over time. The government anticipates that the continued increase in the economy will lead to an increased demand for container handling services at the existing port (Japan International Cooperation Agency,2015b). The historical throughput data depicted through Figure 4.2, shows there is an upward trend in the throughput received at the port since 2005. The bulk cargo handled at the port has increased by 1.5 times from 2011 - 2014 (Japan International

[4] This motivation is particularly interesting as ROA allows for maximisation of the financial value of the decision by the inclusion of uncertainty state variable (in this context demand) within the numerical model.

[5] Additionally, it is the port authority who is the initiator of the port expansion plans and the bearer of the CAPEX for the expansion. Finally, for the scope of a design and an evaluation based graduation research, the additional complexity of modelling the terminal operator's cash flows was deemed out of scope.

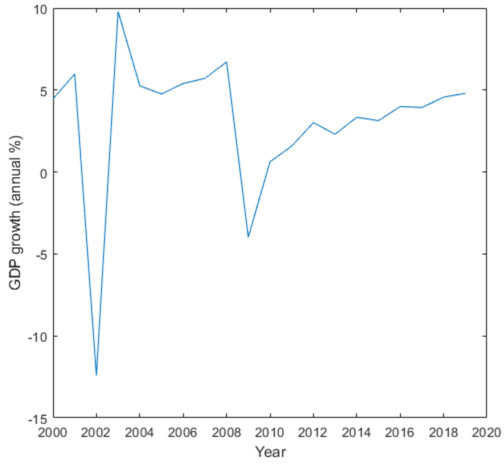


Figure 4.1: GDP change(annual %) trend from 2000-2019 based on The World Bank(2020)

Cooperation Agency,2015b). The current documentation by Japan International Cooperation Agency(2015b), presents that such periods of growth will occur in the coming years.

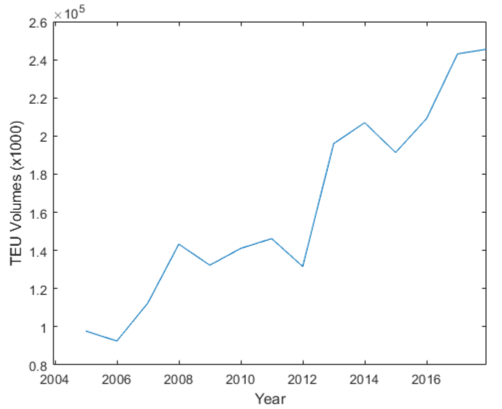


Figure 4.2: Historical Throughput volumes at the Port based on Japan International Cooperation Agency(2015b)

The expectation of the increased throughput coupled with increasing vessel sizes is said to require additional capacity (Japan International Cooperation Agency,2015b) (Japan International Cooperation Agency,2009). Through the expansion of the existing port, the handling capacity of the port and the depths of the berths will be increased and this is said to help in capturing more of the shipping market (Japan International Cooperation Agency2015b).

Based on the points made within Japan International Cooperation Agency(2015b), the port expansion plan involves the following particulars:

- **Breakwater Extension**: The breakwater is planned to be extended up to 345 m in length. This is done to fulfil the optional requirements for the C4 quay and allow for withstanding the waves.

- **Construction of new Quay C4**: The current growth trend in vessel sizes within the Asia-Africa routes, will make the existing quay depth insufficient. To stay relevant, the port is said to require quays that have a maximum berthing depth of -16m. To accommodate calls of larger container ships, the *to be newly constructed* C4 Quay will be 470m in length and -16m in depth.

- **Expansion of existing quays**: The forecasted throughput involves the possibility of calls by deeper vessels of the capacity ranging between 6000-6500 TEU. For carrying out efficient operations, these calls by deeper vessels need to be met with an increased depth of quay and increased numbers of cranes.

Therefore, a total of three cranes are planned to be installed in the existing quays[6]. Additionally, the maximum depth of the quays of C1, C2 and C3 will be increased to -12, -14 m and -16m respectively.

- **Expansion of container yard**: In conjunction with the expansion of quay and crane facilities, the container yard too, requires expansion. The existing container yard spans 10ha of land and an additional 15 ha will be required to handle the expected demand forecast.

4.2.2. Case Model Description

The DCF model developed by Royal HaskoningDHV aids in calculating the cash flows for the port authority and the port operator based on the forecasted volumes. It was developed on Microsoft excel using the FAST (Flexible, Accurate, Structured and Transparent) modelling standard, which considers the planned port expansion investments, throughput scenarios and annual reports of the concerned authorities.

The relevant cash flow calculations involve CAPEX, Development Expenditures (DEVEX) and OPEX , revenue streams and the relevant corporate tax paid. For evaluating the decision based on the cash flow projections, the concept of the time value of money and price escalation has been used. The cash flow projections are discounted for the year 2020.

Model Key Data Description

- *Project Phases and Timeline*:
  The project phases which are considered within the model is depicted within Figure 4.3. For the expansion to take place the development phase precedes the construction phase. The development phase is to start in 2016 and is expected to last for 5 years. After this phase, the construction phase is initiated. The construction phase beginning in 2020 is expected to last for 8 years. The operations phase during the concession period begins in 2026 and lasts for 10 years. Post the concession period (end of 2035), the operation phase continues until the end of 2049.

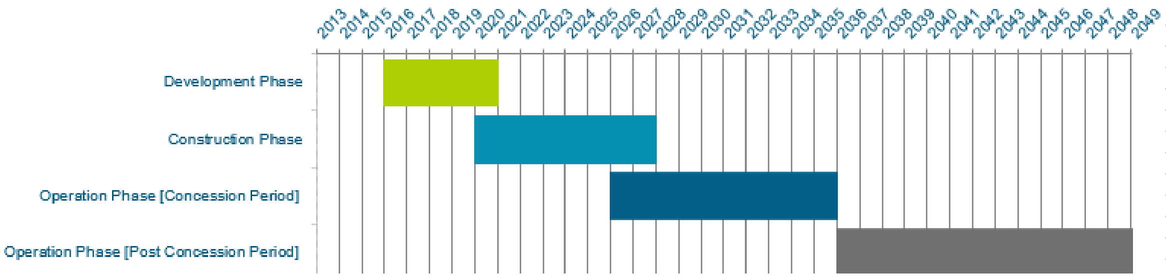


Figure 4.3: Project Phases (illustrated based on HaskoningDHV(2020))

- *Capacity Particulars*:
  The capacity expansion of the port involves both quay and crane expansions. The current theoretical capacity of the port is 4,00,000 TEU and the operational quay capacity is 2,60,000 TEU (65% of the theoretical capacity). The planned quay expansion will increase the theoretical quay capacity to 8,50,000 TEU and the subsequent operational quay capacity will be 5,52,500 TEU. The planned crane expansion involves, the installation of six gantry cranes, each of which can handle 1,00,000 TEU. After the completion of expansion through quay and crane, the port will have a theoretical capacity of 14,50,000 TEU and an operational capacity of 11,52,500 TEU. From Figure 4.4, it can be gathered that the capacity expansions are in a stepped manner[7]. The construction phase is planned in such a way that, the total quay expansion and 3 gantry cranes are operational from the end of the year 2023. The rest of the gantry cranes are installed and operationalised from the end of 2027.

- *Cash Flow Particulars*:
  The investment decision for both the port authority is to understand and analyse the trade-off between the upfront capital expenditures and the anticipated profits within the duration of 2016 - 2050. The cash

[6] The occupancy rate within the existing quays was observed to be 60% in 2014. It is anticipated that this occupancy rate will increase and lead to additional waiting times. To keep the waiting times in check, installation of the three gantry cranes is said to be sufficient.

[7] It is worth noting that, within the current financial model, the stepped capacity expansion is valued as a single project. Therefore, the stepped capacity expansion should not be confused with a flexible expansion. The financial model calculates the business case assuming that the complete capacity is an obligation without an option to abandon.

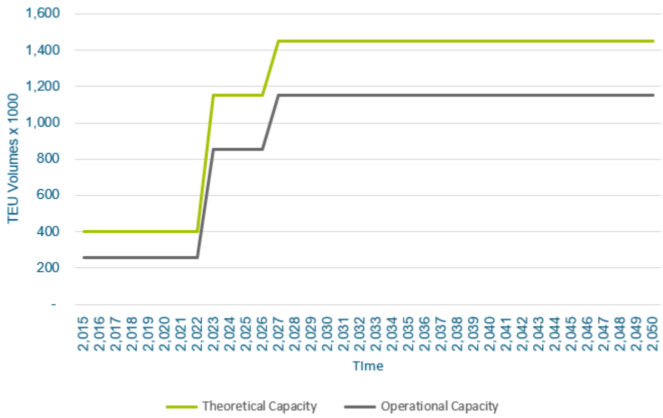


Figure 4.4: Capacity versus time

flow breakdown structure which is used within the financial model is visualised within Figure 4.5. The relevant quantified assumptions for the cash-flow breakdown structure is presented in Table 9.1 within chapter 9.

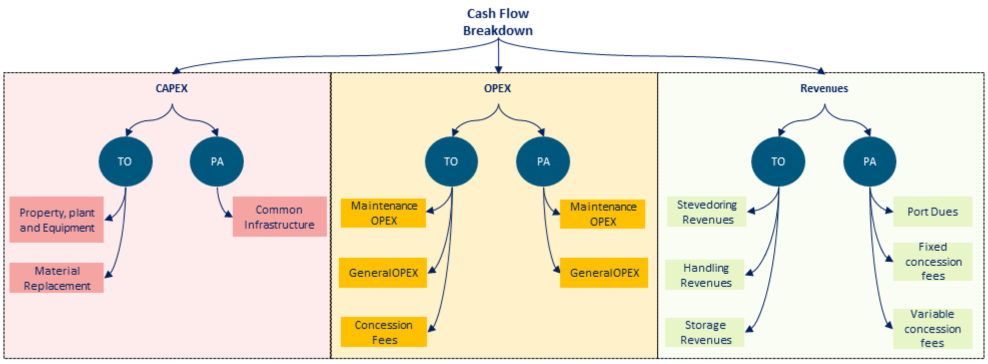


Figure 4.5: Cash Flow Breakdown

Model Results

With this sub-section, the results derived from the financial model is described under the categories of forecasted scenarios, cash-flow(s) particulars and project indicators.

- *Forecast Scenarios* :
  To calculate the relevant cash-flows for the port authority, the current model follows the forecast figures provided by Japan International Cooperation Agency(2015a). Figure 4.6 visualises the total container volumes forecast (in x 1000 TEU) against time. The forecasted volumes consist of three scenarios: optimistic, middle/base and pessimistic. The total container volumes consist of import, export and Transshipment (TS) volumes. Table 4.3, tabulates the forecast volumes for 2020, 2025, 2030 and 2035 (as presented in Japan International Cooperation Agency(2015a), based on the total container classifications according to the scenarios mentioned previously. The forecasted volumes per scenario follow a constant growth percentage. The compounded average growth rate for the period between 2020 and 2035 in total container volumes for the middle, optimistic and pessimistic case is 107.044%, 108.562% and 105.52%. The optimistic case considers that there is an increase of 25% growth and the pessimistic case considers that there is a 25% decrease when compared to the middle case forecasts for each year.

  The forecasts which is shown in Table 4.3 and Figure 4.6, are unconstrained in nature. In an unconstrained forecast, the forecasted volumes are not subjected to supply constraints (Chan,2018). Within this context, the unconstrained forecasted volumes are not limited by the port operational capacity. A plot of the constrained forecast which is limited by the bounds of operational capacity is visualised in Figure 9.4. The pitfalls of the existing forecasted scenarios are explained in subsection 4.2.3.

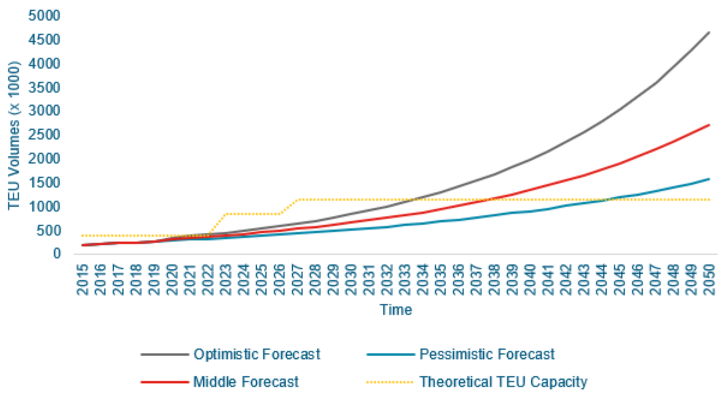


Figure 4.6: Forecast Scenarios(visualised based on Japan International Cooperation Agency(2015a))
The figure visualises the historical volumes from 2015 - 2019 and the forecast volumes from 2015 - 2050 against time. The theoretical TEU capacity shown through the yellow dotted line shows the maximum handling capacity for the port based on the current expansion plan[8].

Table 4.3: Forecast Volumes (2020 - 2035) based on scenarios

Forecast Scenarios	Local Volumes (x1000 TEU) [a]				Transshipment Volumes (x1000 TEU) [b]				Total Container Volumes (x1000 TEU) [c] = [a] + [b]			
	2020	2025	2030	2035	2020	2025	2030	2035	2020	2025	2030	2035
Middle	270	382	539	761	50	78	122	190	320	460	661	951
Pessimistic	247	323	422	552	45	66	96	138	292	389	518	690
Optimistic	296	450	685	1043	54	92	156	260	350	542	841	1303

- **Cash-Flows** : The details on the results of each flow are mentioned in subsection 9.3.4. It is the revenue and the OPEX cash flows streams that vary based on the three scenarios. The decision plan involves installing the total capacity at once. Therefore, the DEVEX and CAPEX is static cash flows unless the project is phased.
- **Project Indicators** : Table 4.4 tabulates the project indicators (NPV, payback period and IRR) which is used by Royal HaskoningDHV to assess the business case.
  - *Net Present Value*
    The project NPV varies based on the active scenario and the variance of NPV within these three scenarios is significant. For instance, there is an increase of 45.2 Million EUR in project NPV when the switch is made from the base to the optimistic scenario. Similarly, the difference between the NPV between the pessimistic and the optimistic scenario is that of 119.65 Million EUR. Therefore, the spread of NPV values between these scenarios is rather large. This significant spread of NPV depicted through three deterministic scenarios is a matter of concern. Figure 4.7, plots the cumulative discounted cash flows against time.

Table 4.4: Key results of the Financial Model operationalised by Royal HaskoningDHV

Description	Unit	Optimistic	Pessimistic	Base
Project IRR	%	1.01	0	0.17
Payback year (excl. financing)	year	2047	Exceeds time horizon	2049
Payback time (excl. financing)	years	27	Exceeds time horizon	29
Project NPV	000 EUR	Positive	Negative	Negative

  - *Project Payback Time and Duration*
    The port within the case study involves a long-payback period with negative NPV values (except for

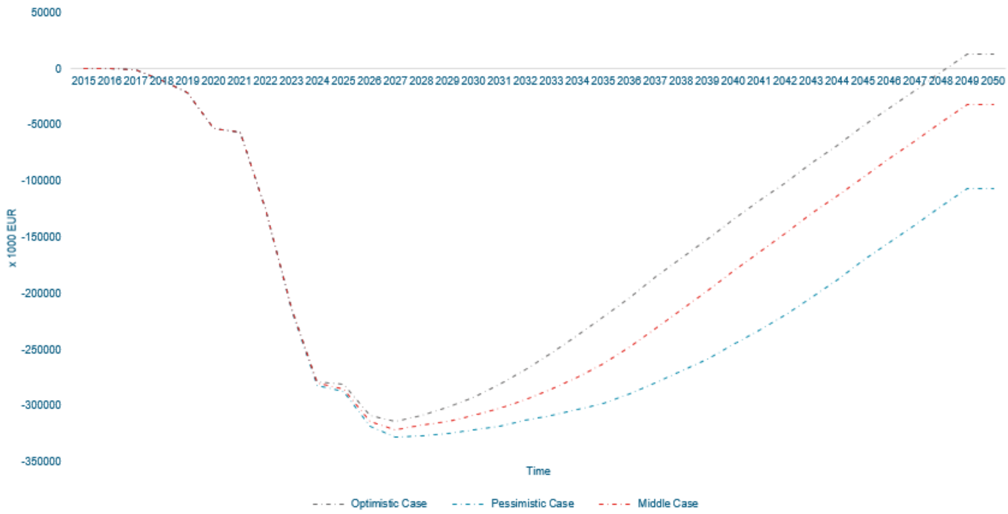


Figure 4.7: Cumulative cash-flows plotted against Time

optimistic scenario)[9]. In the case of optimistic and base scenarios, the payback period is said to be 2047 and 2049 respectively, which occurs at the ending stages of the project timeline. Only, if the assumptions and the forecasted volumes hold, the payback duration will fall within the project timeline.

– *IRR*
The IRR outcomes are only favourable for the optimistic scenario. For the base and pessimistic scenario, the IRR is lesser than the discount rate for the case-study.

4.2.3. Analysis of Case Model

Within this subsection, the assumptions and the results mentioned within subsection 4.2.2, will be analysed and discussed. This is done to have a systematic view of the existing model and identify the potential points of consideration for the design component of the research.

- *On Forecasts and Scenarios*
  The financial model for the chosen case study considers three scenarios of forecasted demand and calculates the corresponding cash flows as a single stream. The consideration of three demand scenarios aids in understanding the different possibilities of project NPV, IRR and the payback time(s). However, the model does not consider alternative decision options. For instance, the current expansion plan can be broken down into smaller parts or modules and implemented throughout the timeline.

  Secondly, the forecasted volumes for the three respective scenarios account for a linear increase. The linear growth percentage can be said to be a point of departure from real-world deviations. Through Figure 1.1, the deviation of actual volumes against forecasted volumes (for a period between 2008 to 2018) can be significantly observed[10]. The presently employed three demand scenarios (visualised in Figure 9.4), considers scenarios with varying growth percentages. The employed varying growth percentages assume that the forecasted volumes will grow with a said value. However, it does not consider the volatility and fluctuations in the demand projections. For instance, future volumes can decrease after a period of continual growth. This variable behaviour of future volumes is not reflected, thereby making the forecasted volumes to be deterministic in nature[11].

  According to de Neufville and Schotles(2011) scenarios needs to be understood as different projections of the uncertain future. The existing forecast used in the model seems to utilise a uniform probability distribution wherein the forecasted volume lie within a particular range. The simplistic use of a range does not communicate the likeliness of one scenario occurring over the other. Use of such ranges which

[9] Refer to Table 4.4 for the quantified values.
[10] Figure 1.1, uses the actual volumes and the forecasted volumes figures for the chosen case study of Port of Toasmasina
[11] The deterministic nature of the forecasts can also be understood as a similar fashion of continual growth without considerations of dips and variations in the forecasted volumes

follow a singular growth curve results in different values of project indicators without considering the volatility around the forecasts. A realistic valuation of the project should be influenced by the variability of forecasts and not different range estimates (de Neufville and Schotles,2011).

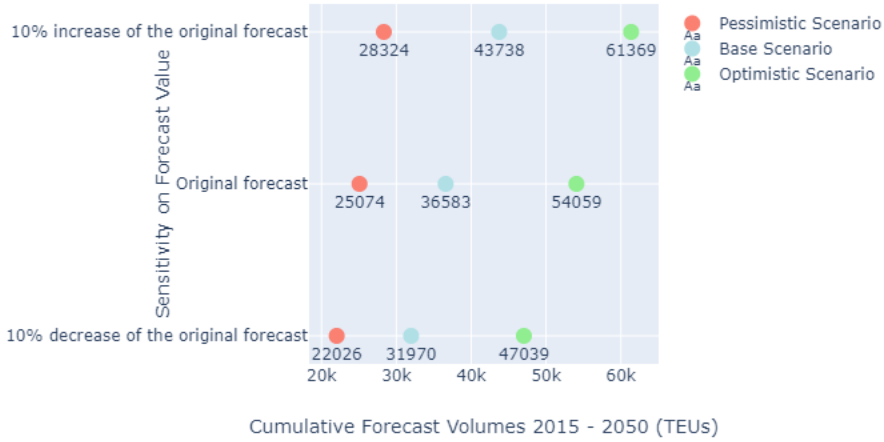


Figure 4.8: Sensitivity of NPV values by varying demand forecast
The visualisation shows the impact of varying the demand forecast by +/- 10% on the Cumulative Forecast Volumes (2015-2050) values for the three scenarios of optimistic, base and pessimistic. There is a 13.5% increase in cumulative volumes within the optimistic scenario when the shift is made from the original forecast to a scenario when the forecast volumes for each year is increased by 10%. While for the pessimistic scenario a similar shift results in a 12.76% increase. This shows that an increase or decrease in the demand forecast results in varying cumulative volumes which might prove to be significant while calculating the cash flows.

Fourthly, the resultant cash flows calculated within the financial model is heavily influenced by the assumptions employed within the forecasted figures. To understand the sensitivity around the forecasted volumes, the figures of forecasted volumes were varied by a percentage of + and - 10%. Figure 4.8, visualises the inability of the three scenarios to consider varying demand for each of the scenario. The effect of varying demand forecast was observed by the resultant NPV values for these sensitivities and visualised in Figure 4.9. Through Figure 4.9 the jumps in NPV values can be significantly observed. For instance, when the demand forecast is increased by 10% of the original forecasts, the new NPV values for the optimistic scenario is seen to increase by 113%. While for the pessimistic scenario when the demand forecasts are increased by 10% the NPV value only increases by 26.63%. The telling shift in NPV values can be worrisome when the forecasts reduce by 10%. For the optimistic scenario, a 10% decrease in forecasts will result in a reduction of 132% in the final NPV value. This shift in NPV values highlights the sensitivity of the assumptions involved within forecasts.

This sensitivity requires additional consideration which a stand-alone DCF model cannot satisfy. The DCF approach adds unreliability by not considering numerous scenarios, staging options, probabilities of occurrence and sensitivities that a RO model can. DCF follows a predict and control approach. It is realised that the odds of forecasting high confident point estimates of future cargo volumes are slim. However, treating the demand variable to be a static variable does not contribute to the cause. By a stochastic evaluation of the demand variable, the set expansion magnitude can be verified. A deeper stochastic consideration into the volatility of the demand parameter can be said to aid in capturing uncertainty within the valuation model.

- *On Cash Flows*
  The financial model considers CAPEX, DEVEX to be static components and OPEX , Revenues components to variable components. The variable components vary based on the chosen three demand scenarios. Moreover, the model is set up using the FAST (Flexible, Accurate, Structured and Transparent) modelling standard, which allows for changing key inputs. Although there is the flexibility to change the

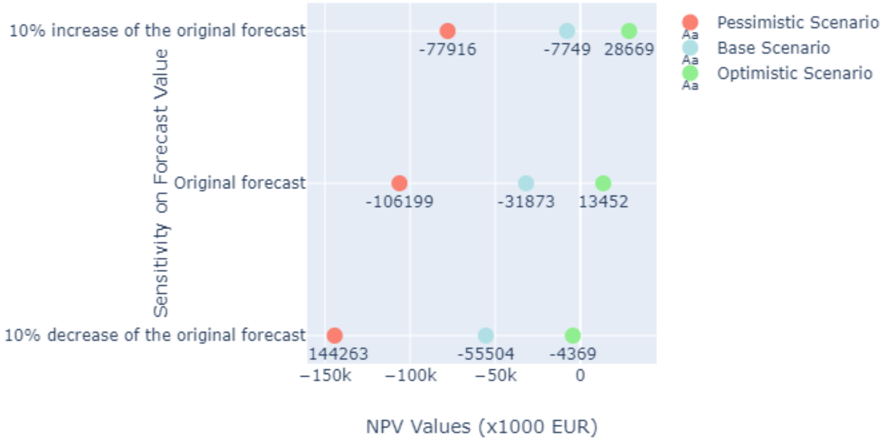


Figure 4.9: Sensitivity of NPV values by varying demand forecast
The visualisation shows the impact of varying the demand forecast by +/- 10% on the output NPV values for the three scenarios of optimistic, base and pessimistic.

inputs, the outputs are heavily dependent upon deterministic input parameters. It can be claimed that the deterministic cash flows can account for demand uncertainties by conducting in-depth sensitivity and scenario analysis. However, for the chosen case study the demand uncertainty is not captured thoroughly.

The financial model employed for the decision making is a DCF model which is employed to value the future cash flow and is thus a forward-looking methodology (Steiger,2008). According to Steiger(2008), such a methodology relies heavily on the underlying assumptions and the prediction of the future. The same notion of DCF valuation model can be seen to apply to the existing case model. The cash flows that are calculated within the valuation model is a single projection of reality using a limited number of scenarios. It can be remarked that the changes in assumptions of cash-flow calculation will influence the valuation model result and the existing three scenarios will not be sufficient to present the range of future outcomes.

Although the existing DCF model provides the benefit of being a simple and sound methodology to calculate the cash-flows, the DCF has been criticised by Myers and Brealey(1995), for the lack of consideration of endogenous and exogenous project-related uncertainties. The use of a discount rate used within the DCF is not in itself enough to capture the uncertainty around the demand forecast (Balliauw et al., 2019b). Although the current model utilises Weighted Average Cost of Capital (WACC) for discounting the cash flows, it only considers the “risk” component but not “uncertainty”.

- *On Project Indicators*
  The expansion plans initiated by African Port can be said to lucrative (in terms of pay-offs) if the forecasted demands for the optimistic scenario are met. Scenarios that involve lesser volume projections than the optimistic scenario will yield lesser pay-offs. de Neufville and Schotles(2011) claim that a scenario analysis conducted for a deterministic scenario fails to consider that, the management will not adapt their decision making. For instance, if the market performs poorly, it can be expected that the port authority will alter the design and expansion plans. Therefore, this adaptability of expansion plans in terms of their associated monetary values is not reflected in the current financial model.

  Incorporating flexibility through the valuation of expansion options by creating a range of future’s through the simulation of demand parameter, might provide an incentive to delay/phase the project. If the demand volumes increase while the port authority waits, the decision-maker can pursue to expand with confidence in generating the associated pay-offs. However, if the demand value does not increase, then the decision-maker can simply wait and operate the existing capacities (thereby reducing their exposure to the potential losses). The 8 years of construction time provides an opportunity to try different timings of investments along with varying magnitude(s) of expansion allowing for flexibility. The problem of the current decision maker within this case can be said to maximise their project outcomes by choosing an optimal expansion plan (both in terms of timing and magnitude) and also realise their objective of rejuvenating the maritime transport through competitively positioning the port within the international and regional logistics chain. There is a need for a project plan which is dynamic and responsive to the developments within the project environment. As shown by Taneja et al.(2010), such a need can be fulfilled by considering demand or price uncertainty within the valuation model.

4.2.4. Conclusion of Case Data Exploration

The expansion decision for the Port authority is contingent on the assumptions made for forecast, timing, cash flow calculations. Although the above paragraph critically analyses the existing model, it must be realised that the robustness of the decision process matters more than the solution in itself. The current research recognises the importance of a flexible and adaptable decision process and attempts at linking this to the valuation model by the implementation of ROA.

The current DCF model gives an impression that the decision-maker is obliged to the complete project expansion timeline and cannot change the plans at a later date. Additionally, it assumes that, the decision-maker is a *passive manager* resulting in static expansion plans (Damodaran,2012). It must be noted, the reality is otherwise, the decision-maker is an *active manager*, who adapts the development/expansion plans to the changes based on the project progress (Damodaran,2012). For the Port Authority of the African port, the expansion of the port is a part of the development plans for the country which is expected to boost the economic and commercial development of the country. Additionally, the project is financed using a loan from Japan International Cooperation Agency (JICA). The investment consultant for this case mentions that the port authority is trying to invest in plans based on resources that are best available to them.

The desire of the port authority to stay competitive and adapt to the developments comes with the price of long lead time and huge upfront capital expenditures. Although the expansion is said to radiate benefits to the regional and national economy, the competition from the neighbouring international ports within the region adds to the complexity. According to the analysis of Flyvbjerg et al.(2003), it can be anticipated that, like many large-scale transportation infrastructural projects, this expansion project might also face cost-overruns during the implementation stage. It is the deterministic forecast along with a static expansion plan which is an issue that might not lead to the intended benefits. Within the existing model, it is observed that it is only the optimistic scenario that can generate favourable project outcomes. For the pessimistic and base scenario, the NPV is seen to be negative and the IRR values do not exceed the cost of capital. It is not the polarity of NPV which is an issue, but it is how the expansion is valued through a financial model. There is a possibility that the current financial model is either undervaluing or overvaluing the resultant cash flows from the investment decision. The current three scenarios do not highlight the likelihood of the scenarios and present a broad range of values. For instance, the spread between the optimistic and pessimistic scenario is 119.651 Million EUR.

The further parts of the research will be focusing on designing a valuation that considers the analysis derived from the discussion of this section. More specifically, the valuation model through RO methodology should consider the following aspects:

1. Based on the existing methods of ROA within literature and case study background, a flexibility capacity planning approach for the port will be designed.

2. The modelling approach should be able to consider the uncertainty parameter of demand in a stochastic manner. This will allow for a forecast which reflects the volatility of the chosen parameter.

3. The port expansion problem will be formulated as an optimization problem wherein the solution consists of the optimal magnitude of expansion along with the optimal moment of investment decisions.

4. Additionally, the decision-maker will have other possible options of expansion which can be used as adaptable options in case the developments of the short term future positively or negatively affect the project context.

4.3. Conclusion of the Chapter

The summary of the port planning process and the following decision-making process is visualised in Figure 4.10. The interviewees state that port planning involves long periods of the decision-making process. The process of port planning involves strategic objectives wherein the client aims to realise short-term and long-term objectives. The interviewees claim that during the ideation and pre-feasibility stages, these objectives are at times ambiguous and the intent is weakly formulated. All the interviewees maintained that the decision making is fairly iterative and involves many decision-makers. From the results of the exploratory interviews,

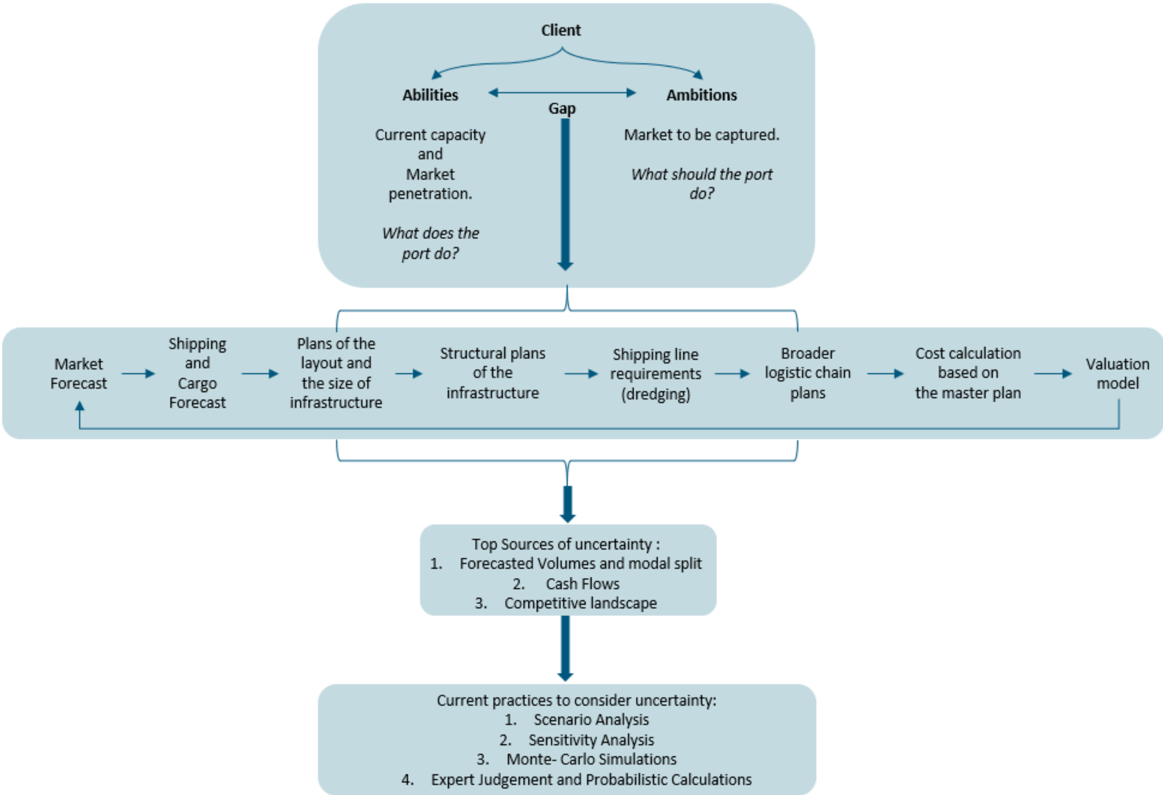


Figure 4.10: Port planning and the subsequent decision-making process

The port planning process starts with assessing the gap between abilities and ambition. The consultants during the feasibility stages work in iterative cycles to develop a business case. The figure also mentions the sources of uncertainty that affects the business cases. Finally, the current techniques to consider these uncertainties have been mentioned.

it can be claimed that it is the market forecast which influences the outcomes of a financial model. Market forecasts are said to be a significant factor that is used for creating business cases for long-term planning objectives. However, these forecasts are indicative and cannot be predicted with certainty. These forecasts can be significantly influenced by invalidated assumptions and are prone to opportunistic manipulation by the decision-maker. All the interviewees held the belief that forecasts are to be considered as a certain expectation of the future and cannot be treated as an accurate measure. Apart from market forecasts, uncertainties stemming from price and competitive behaviour can be said to be the following top sources of uncertainties. These parameters cannot be measured with certainty due to the lack of data and heuristics. Considering the relative uncertainty involves, it might be counter-intuitive to employ the static DCF model. However, it was understood that for the industry the traditional valuation techniques have stood the test of time. The accompanying techniques of Monte-Carlo analysis, sensitivity analysis and scenario analysis are said to communicate the various positions of investments under different conditions. Additionally, each project is said to come with its own set of requirement and associated time and budget.

A similar perspective is also seen in the financial model for the case study. The model is seen to employ a single point estimate of forecast volumes which are only increasing as time progress. Although there is a presence of three scenarios, they consider only varying growth percentages. The financial model although being flexible to consider different input values, the “Now or Never” mentality seeps into the decision model.

The three scenarios of project indicators do not inform on the likelihood of the scenarios and alternative strategies in case of sluggish growth. This case study's objective for Royal HaskoningDHV was to conduct a high-level analysis of the cash flows associated with the expansion plan. The financial model was built using the existing data provided by the client.

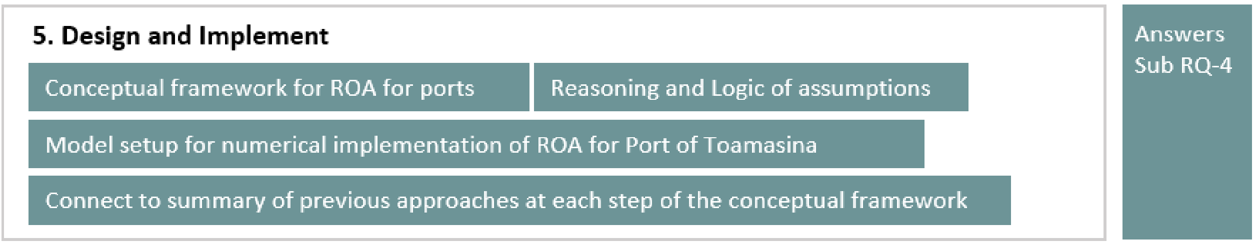
This case study is a representative example of the high-level analysis required by consultants during the feasibility stages. Secondly, the outcomes of the decision model are to be communicated and reported within a certain budget and deadline. These externalities favour a static DCF approach with fairly done scenario and sensitivity analysis. Finally, it can be claimed that the use of valuation techniques used within port decision making is not based only based on the complexity of the case. Rather it is the kind of analysis that can be easily reported and communicated with actionable insights within a short period.

Relevant Takeaways for further chapters

From the exploratory interviews, the sources of uncertainty will be used while designing the framework. Both based on the observations made in theoretical background and the exploratory interviews, it is uncertainty surrounding the throughput projections which is frequently cited. Secondly, according to Triantis(2005), there is a requirement to make ROA approaches practically relevant by using the tools which the practitioners are familiar with. Insight from the interview on the current protocols to consider uncertainty will be used and discussed while devising the framework. The tools are not limited to expert judgement, Monte-Carlo simulations, probabilistic analysis, scenario and sensitivity analysis. Thirdly, when the concept of ROA was introduced to the interviewees the following question arose: *"What is the level of sophistication required? Where to get the data from? How can the quality of data be assured or validated? What is the quantity (years) of data required?"* These questions will be used in the discussion section of research(chapter 7). Based on the analysis of the case study for Port of Toasmasina, it is observed that a variation in demand can result in significant differences in NPV. It is the uncertainty around the future throughput volumes that will be used within the numerical model setup of ROA. Finally, the project indicators and the details of the expansion from the case of African Port will be used for the comparative analysis.

5 Develop Phase

I can live with doubt and uncertainty. I think it's much more interesting to live not knowing than to have answers which might be wrong.
— Richard P. Feynman



In this chapter, the develop and the implement phases of the research are presented. The first half of the chapter presents the devised conceptual framework for ROA for port applications. This is partly achieved by, using the takeaways from chapter 3 consisting of a discussion of ROA methodologies and summary of implementation approaches of ROA within infrastructural (especially ports) decision-making applications. Additionally, the insights from the interviewees on the uncertainty parameters and nature of port decision making, are also used to reason some of the assumptions within the conceptual framework. The latter half of the chapter consists of the numerical model which has been set up for the African Port. This numerical model is set up by executing the steps of the conceptual framework.

The relevant takeaways derived from the chapter include:

1. A conceptual framework which is contextualised for port infrastructural decision making. Additionally, the relevant assumptions and process mechanics for the application of ROA for ports.

2. Reasoning and Logic for the numerical implementation of the conceptual framework. the specifics of the process mechanics for the case study.

   Through the takeaways from the conceptual framework the following sub research question has been answered:

   - **Sub RQ-4**: How do the published implementation approaches and the requirements lead to a real options application for port infrastructures?

   The takeaways from the conceptual framework will be further utilized in the discussion (chapter 7) sections of the report. The results derived from the numerical model implementation for the case study will be presented in chapter 6.

5.1. Conceptual Framework

The first part of the section presents a high-level description of the conceptual framework. A more detailed description of each stage of the conceptual framework is described and discussed in the second half.

5.1.1. Background

Based on the review of literature conducted in the theoretical background section, it is the uncertainty in demand which is used in a significant number of applications. 12 out of the 17 reviewed articles on ROA in transportation infrastructure, use demand as a parameter of uncertainty. Through the exploratory interviews too, it was the uncertainty around throughput volumes that were cited most frequently. Transport infrastructure can be said to be built around a certain expectation of future demand. This future demand most significantly influences the baseline financial outcomes of the decision plans. However, the consideration of demand or price uncertainty will not affect the nature of the conceptual framework. It is the availability of data that dictates will dictate the use of the proposed framework for modelling price or demand uncertainty.

Within infrastructural applications of ROA, the most frequently employed methodologies for ROA involves either lattice or Monte-Carlo simulations. Monte-Carlo simulations are more prominently used in infrastructural applications. Monte-Carlo simulations as a forward-looking technique allow for the consideration of numerous scenarios. Additionally, such an approach has been seen to be frequently used due to its simplicity and theoretically grounded approach for solving for RO. Within port implementations, Taneja et al.(2011), Reyes et al.(2019) and Lagoudis et al.(2014) use Monte-Carlo simulations based approaches. However, it is only Lagoudis et al.(2014) wherein ROA is implemented for flexibility “on” ports. Hence, the proposed conceptual framework uses the work of Lagoudis et al.(2014) to verify the nuances of the assumptions. Further approaches to model RO for infrastructures by de Neufville and Schotles(2011), de Neufville et al.(2005) and Geltner and De Neufville(2018) are used to sharpen the modeling guidelines presented in the conceptual framework. These guidelines especially relate to the choice of stochastic process, discount rate assumptions and probability calculations.

Approaches employed by Elvarsson et al.(2020) and Cardin et al.(2017a) will be used in framework to interpret the results of Monte-Carlo Simulations. Based on decision rules and objectives, the optimal moments of investments and the magnitude of investments are calculated using. Finally, the approach to calculate value of flexibility, is utilized from Cardin et al.(2007).

5.1.2. High-Level Description

The existing RO models for port infrastructural systems are limited in terms of the assumptions and their practical relevance. Lagoudis et al.(2014) and Reyes et al.(2019) are some of the instances of research which uses data from an existing port to model the decision making using ROA. In terms of the process mechanics, most of the published works in RO consider demand uncertainty and use a combination of random walk and Monte-Carlo Simulations in their implementation of ROA. The prevalence of demand uncertainty was verified in the exploratory interviews.

Exploratory interviews allow the conceptual framework to be modulated using their perspectives on uncertainty and the influence of uncertainty on financial outcomes. Additionally, the availability of real-time values from the case study adds perspective while defining the conceptual framework. Incorporation of these perspectives on theoretically grounded ROA literature can be anticipated to allow for a methodology that can be implemented based on real-time availability of data, assumptions and decision-making requirements. The proposed conceptual framework is visualised in Figure 5.1 consisting of five broad steps.

- Motivation for the Conceptual framework:
    - *Practical relevance:* One of the frequently mentioned limiting factors of ROA is its lack of practical relevance, the opaqueness of assumptions and the involvement of complex mathematics. The existing approach used by practitioners at Royal HaskoningDHV involves the use of Microsoft Excel for modelling the cash flows and the financial outcomes for a project. To tailor ROA for its practical relevance it is required that, the application is also done using the tools which are most commonly used in practice. The RO framework is formulated using elements of spreadsheet, decision rules and Monte Carlo simulation methods. This allows for devising a numerical methodology on a platform i.e. Microsoft Excel which the practitioners are well-versed in. The conceptual framework intends to implement ROA by enhancing the current static DCF model.

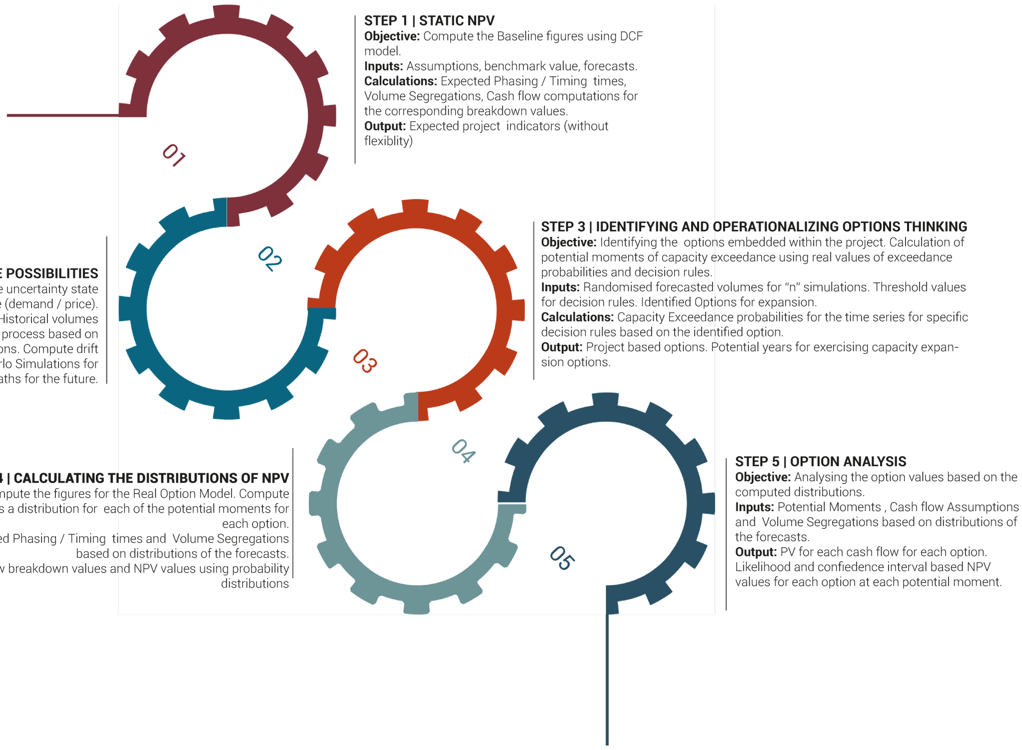


Figure 5.1: Complete framework for Real Options analysis for decision making for port infrastructures
This framework highlights the overall steps involved for devising a real options analysis model for a given port case. It is grounded based on previously implemented approaches and recognises the dynamics of port infrastructural decision making as derived from the exploratory interviews.

  - *Comprehensibility:* The assumptions in a binomial, MAD or the classical approach can be said to require a deeper understanding of the options pricing nuances. For instance, during the ideation and pre-feasibility stages in public port infrastructural decision making, arbitrage[1] opportunities cease to exist which makes the replicating portfolio assumption invalid. Based on the results of the exploratory interviews, it can be claimed that such assumptions will make it difficult for the practitioners to work such ROA models. Instead, the current conceptual framework is devised in such a way that it can be added to a static DCF analysis without adding new structural assumptions.

- Use Case Information:
  - The conceptual framework is devised particularly for brownfield projects. Firstly, ROA is not a forecasting methodology but a methodology to analyse alternative options of investments. Brownfield projects allow the availability of historical data which can then be used to simulate future paths using a more probabilistic process. A greenfield project on the other hand requires a deeper market and macro-economic analysis for developing an estimated forecast. This deeper analysis is considered to be out of scope, hence, the current research focuses on brownfield projects.
  - Although primary attention is paid to demand uncertainty, the current framework considers the existence of price-related uncertainty. The previous works of Geltner and De Neufville(2018) and Zhao et al.(2004) use Monte-Carlo for considering price-related uncertainties. These price-related uncertainties can be related to material, construction and equipment costs. Therefore, the framework can be customised to the case of application.
  - The objective of the conceptual framework similar to the previous works of Balliauw(2020) is to identify the optimal moments of investments that can allow for maximisation of expected net-payoffs.

[1]A no-arbitrage assumption involves that the asset is valued solely based on the value of the asset without considering alternative fluctuations in the market. For instance, a case of arbitrage involves when a stock is purchased in New York Stock Exchange and is then sold in London Stock Exchange for a higher price. This is called a situation of arbitrage. A no-arbitrage assumption involves the valuation of the asset without market-related price discrepancies.

Additionally, Reyes et al.(2019) and Taneja et al.(2011) the objective of this conceptual framework is evaluate the benefit of a flexible alternative (staging) over an inflexible plan.

5.1.3. Static NPV

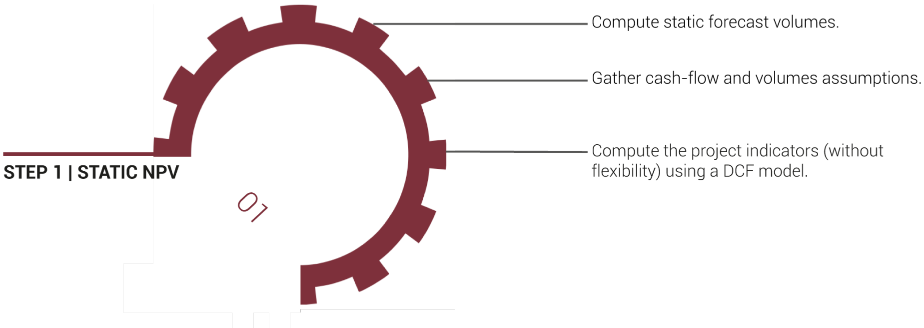


Figure 5.2: Step-1 of the conceptual framework with required sub-steps involved in the process.

- Objective: Compute baseline figures using static DCF valuation.
- Description: To implement a real options methodology, it is first required to have a baseline DCF financial model. The presence of a static DCF model indicates that the decision-maker has not exploited the flexibility present in the project (Guthrie,2009a). The steps involved in this step is visualised in Figure 5.2. The financial model should consist of the cash flow calculations and assumptions. It is this static DCF model which will be extended to a real options valuation model. The results of this valuation model will be used for flexible decision making.

5.1.4. Estimation of Future Possibilities

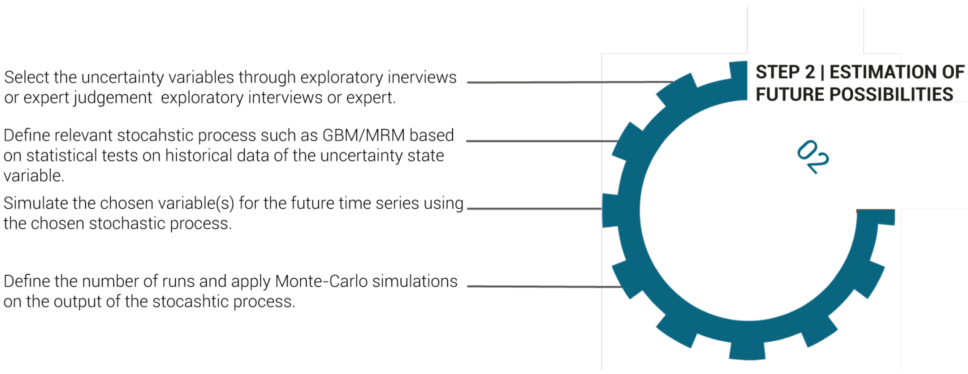


Figure 5.3: Step-2 of the conceptual framework with required sub-steps involved in the process.

- Objective: Selection and Simulation of uncertainty state variable for the project timeline.
- Description: The flexible decision model extracts its benefits from forecasting time series for the chosen uncertainty variable. The processes involved in this step is visualised in Figure 5.3. Within port infrastructural decision making, it was observed that the major source of uncertainty stems from future throughput volumes and price related uncertainties (refer to the results of exploratory interviews in section 4.1 and theoretical background subsection 3.2.3). Balliauw(2020), uses demand as a major source of uncertainty for the implementation of real options for port expansions. Salminen(2013), use demand as the chosen uncertainty state variable for a case of port development decision for southeast Asia. In other infrastructural applications by Buyukyoran and Gundes(2018) and van den Boomen et al.(2019)

price uncertainties are taken into account. The decision to select uncertainties can be done using exploratory interviews (as done within this research), else the knowledge of local experts can also be used to determine the sources of uncertainties. Salminen(2013) considers groups uncertainty into two sources, one is said to be the trend and the other is the trend-breaker. A trend is determined from the historical data of prices or demand. Whereas a trend breaker allows considering specific probability for events such as a change in the political landscape or extreme natural events. Such considerations can be made in cases where there is the availability of statistically significant and relevant data repositories.

This conceptual framework based on previous works recommends simulating the future possibilities by using a stochastic process. Significant number of ROA works (such as van den Boomen et al.(2019), Lagoudis et al.(2014, Balliauw(2020 etc.) use stochastic processes for determining future possibilities for the chosen uncertainties. GBM has been used as a stochastic process in the fundamental works of options pricing Black and Scholes1973 and Cox et al.1979. A GBM is a stochastic process that considers that the underlying variables move continuously in time in a partial random or unpredictable manner. The use of GBM is significantly used to describe the uncertainties within real options analysis (de Magalhães Ozorio et al.,2012). The other alternative to GBM is the application of Mean Reversion Models which is used within options pricing for both financial and real assets as seen in Schwartz1997 and Dixit and Pindyck1994. Contrary to GBM, an MRM considers that the uncertainties (especially price related) wander randomly within the short-term; however, in the long term, the variable converges to the equilibrium or mean value (de Magalhães Ozorio et al.,2012). The choice between GBM or MRM is determined based on fitness to application and statistical tests (de Magalhães Ozorio et al.,2012). Additionally, the project lifetime along with the compatibility of the stochastic process with the type of solution (analytical or numerical) also plays a role to choose between GBM and MRM. However, it has been observed that GBM has been one of the common stochastic processes used in academic works of ROA especially in port infrastrcutal applications (for instance Lagoudis et al.(2014, Balliauw(2020, Balliauw et al.(2019b, Salminen(2013 and Meersman(2005). The stochastic processes of GBM or MRM result in a single forecast for the future. RO approaches (such as binomial trees or lattice approaches) is limited due to the dimensionality of node outcomes. However, combining GBM or MRM with Monte- Carlo Simulations allows for calculating multiple scenarios by repeatedly picking values from a probability distribution for uncertain variables. The use of Monte Carlo simulations in real options applications are meant to imitate real-life systems analytically (Mun,2002). Using Monte-Carlo simulations results in the calculation of the likelihood of various forecast figures and also help in bypassing the plague created due to "flaw of averages".

- Limitation(s): To simulate the future possibilities using a GBM or MRM with Mont-Carlo simulation there is a requirement that the port consists of historical data for the throughput volumes or prices. Through the historical data, the drift and volatility parameters for the stochastic process can be calculated. However, historical data will be only available for brownfield projects. Therefore, such an approach to estimate the future possibilities is only limited to brownfield projects and does not apply to greenfield projects. Although regional/neighbouring volatility rates could be used as a substitute value, however, this assumption in itself will be uncertain for the said uncertain future throughput volumes. Through the exploratory interviews,it was recognised that many ports may not have the expected magnitude of data for historical throughput volumes. Hence, the applicability is limited to a subset of brownfield projects wherein there is a presence of historical data.

5.1.5. Identification and Operationalization of options thinking

- Objective: Identification of options embedded within the project and the calculation of timing moment(s) for all the relevant expansion option(s).

- Description: This phase involves framing the decision problem in terms of options. Based on the project decision problem the decision-maker needs to define whether the objective is to add real options "in" or "on" projects. This conceptual framework is focused on providing the decision-maker with flexibility through optimising the operations at the port or altering the scale of investments based on future projections. Therefore, the framework is focused on real options "on" projects. Real options "in" projects as mentioned before focuses on instilling flexibility within the design aspects of the port sub-systems. This would require the expertise of the technical design team and master planners to add flexibility during the design stage.

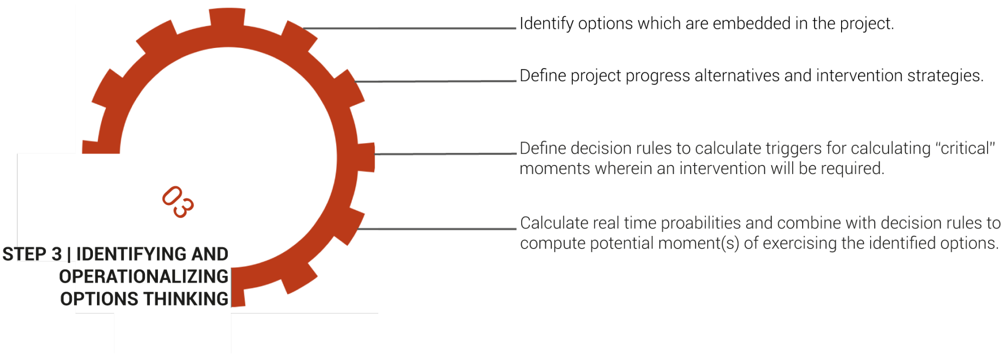


Figure 5.4: Step-3 of the conceptual framework with required sub-steps involved in the process.

– Candidates of flexibility
According to Taneja et al.(2011), the examples of options within the port industry are presented in Figure 10.1. According to Taneja et al.(2010), these options might not be recognised by port authorities as they are used to a static approach of the "now or never" valuation model. To operationalise options thinking, a combination of the questionnaire of Taneja et al.(2010) and the screening model of de Neufville and Schotles(2011) is proposed. Both of these techniques were found useful in a port context in a two-fold manner. Taneja et al.(2010) questionnaire will instigate the concept of real options thinking in the minds of decision-maker. The questions will allow the decision-makers to set the context of options that can be embedded in the project decisions. The questionnaire by Taneja et al.(2010) helps in framing the relevant options based on five categories: establishing success criteria, identifying managerial options, identifying design options, identifying operational options and setting up decision rules. This questionnaire is tabulated in Table 10.1. Secondly, the screening model by de Neufville and Schotles(2011) will allow the decision-maker to understand the functional interdependencies of the system. The screening model by de Neufville and Schotles(2011)is defined to be a " simple, understandable representation of the performance of the system or project under development". Moreover, the screening model will aid in understanding the different investment strategies in terms of flexible options (Salminen2013). Taneja et al.(2010) recommend the use of screening models to develop adaptation and design paths within the project timeline for creating the said value of flexibility. The result of the questionnaire and the screening model can be referred to as "option candidates (with or without flexibility)".

– Setting of Decision Rules
Once there is a list of option candidates for the project, it can be then framed into a conceptual decision tree. The decision tree allows the creation of different pathways with intermediate stage gates for the decisions. The intermediate stage gates can be formed based on clearly formed mathematical decision rules. In this context of port expansion decision making it can be said that the formulation of decision rules will allow in mapping the observations or behaviours of the uncertainty state parameters to actionable insights (Shapiro et al.2009). Decision rules are seen to be used within real options applications for multi-stage expansions with an underlying stochastic process (Cardin et al.,2017a) (de Neufville et al.,2005) (Kuhn et al.,2008). The decision rules employed by Cardin et al.(2017a) and de Neufville et al.(2005) calculate trigger points where there is a set expectation that the future demand will exceed the installed capacity. A similar trigger-based decision rule is proposed within this conceptual framework. The results from subsection 5.1.4 (Step -2), consists of n (where $n \in \mathbb{N} \& n > 0$) simulations which is the result of Monte-Carlo simulations of stochastic processes of GBM or MRM. These n simulations present n possibilities for each year's throughput. The possibilities can be used to calculate the probability of future volumes exceeding the existing installed capacity at the port. Calculating these probabilities will result in the moment(s) of exceedance wherein a suitable expansion strategy must be put in place. It is assumed that the decision-maker is sensitive to congestion and under capacity. Hence the moments where the capacity exceedance is probable at set confidence, the decision-maker has the option to exercise the expansion option. Delaying the expansion investment post these potential moments of investment can be said to result in potential losses in captured volumes which can be seen in the financial model. In this case, real probabilities of exceedance must be calculated. Risk neutral probabili-

ties are calculated based on the no-arbitrage and risk-neutral approach wherein all the arbitrage opportunities are removed by constructing a portfolio that replicates the options. However, in the case of large infrastructural projects, there exists no opportunities to short sell on real options and earn profit through arbitrage Wang and De Neufville2005. Port infrastructural projects fit in the umbrella of are large infrastructural projects. And the net pay-offs of the projects cannot be perfectly replicated by a perfectly traded asset. Therefore, this conceptual framework follows the argument of Wang and De Neufville2005 of using real probabilities to result in actual valuation through risk-adjusted discount rates. Through the decision rules, the project timeline is filtered for the potential moment(s) of (re)investment unique to each option candidates.

- Limitation(s): Identifying option candidates for real options "on" projects can only aid in valuing opportunities which can increase the attractiveness of the financial viability of the project (Wang and De Neufville,2005). Therefore, it is the current operations and the current design on which these option candidates are rested upon. Systemic flexibility cannot be expected from the identified options. The decision rules for capacity exceedance can be subjective. Each decision-maker might have a different attitude(s) towards risk which can influence the calculation of critical moments of exceedance. There are chances of manipulation based on the boundary conditions for decision rules.

5.1.6. Calculation of Cash Flows and Distributions

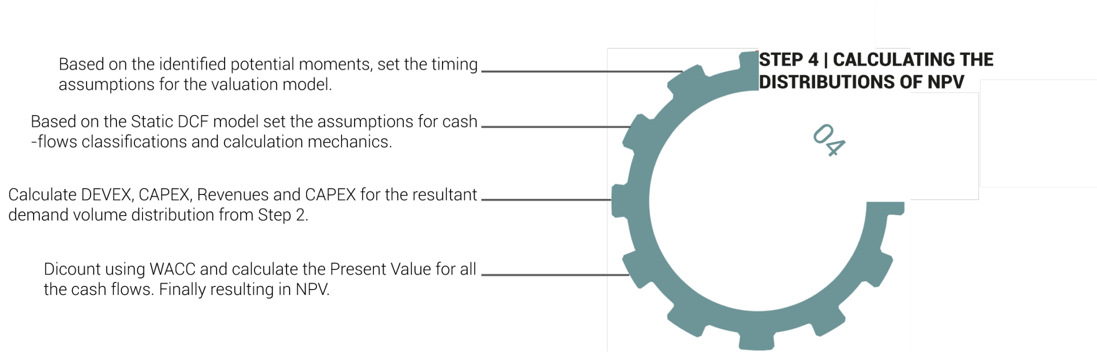


Figure 5.5: Step-4 of the conceptual framework with required sub-steps involved in the process

- Objective: Computation of the cash-flows as a distribution for all the option.
- Description: A port expansion valuation model consists of in-depth cash flow calculations. The complexity of the cash-flow calculations in terms of the number of variables is displayed in the works of Reyes et al.(2019) and Salminen(2013. The complexity stems from the consideration of variable and fixed components of cash flows. However, these authors consider fixed and variable components of the cash-flows. They also use TEU factors and scale demand forecasts.

  Following a Monte-Carlo simulation-based approach requires the simulations of the underlying uncertainty parameter is carried across to the cash-flow calculations (Geltner and De Neufville,2018). The demand parameter involves an embedded stochastic process along with Monte-Carlo simulations. To make the model stochastic, all the simulations need to be used for calculating the cash flows. This will help in adding the dynamic characteristic to the cash-flow model. Replacing the future uncertainty parameter values with the mean value of the parameter is not advised and will lead to erroneous calculations. Using the mean value will expose the calculations to the flaw of averages. Additionally, using confidence values such as P25, P50 or P75 will not allow in calculating the true distributions of the cash-flow values.

  The potential moments of investment from step 3 allows in calibrating the timing assumptions which is to be used to calculate the cash-flows. The potential moments will allow in timing assumptions for the capital outlay(CAPEX), OPEX concession agreements and revenue calculations based on capacity. The cash-flow assumptions such as tariffs of the static DCF model is to be operationalized in the ROA. These assumptions do not change in ROA implementation. The current conceptual framework does not consider the assumptions of risk-neutrality or no-arbitrage conditions. Rather an engineering-based approach based on de Neufville and Schotles(de Neufville and Schotles) and de Neufville et al.(2005) is used. Therefore, the cash-flow streams are to be discounted using risk-adjusted discount rates or WACC. Similar discount rate have been used in the previous implementations of Taneja et al.(2011) and Lagoudis et al.(2014. The process of computation of NPV distributions is required to be repeated for all the options at each of the identified time moments.

5.1.7. Options Analysis

Objective: Computation of option value for all the alternative strategies. Comparison of the alternative strategies to find the optimal strategy.

Description: This step is the extension of the previous step as it analyses the distribution values. The analysis is expected to filter the current time combinations for each of the options which can then be used to calculate the expected Mean NPV value. Secondly, based on these filtered results, further analyses can allow in defining the optimal paths of decision making specifying the time and magnitude details for the decision-maker. Alternatively, the routes can be ranked based on their performance which can be then further aligned to the objectives of the decision-maker. The following are some of the analysis which is observed especially for a Monte-Carlo approach:

- Much ROA applications focus on maximising expected NPV or net pay-offs. For instance, in port applications, the objective of Taneja et al.(2011) was to maximise the expected NPV.
- While in some applications, such as Mittal(2004) focused on selecting alternatives with maximum expected NPV and minimum standard deviation of outcomes.
- Applications such as Balliauw(2020) calculate optimal strategy by maximising profits and calculating the last time moment after which investment will result in lowered net payoffs.

Therefore the decision-maker can choose their optimisation criteria: maximise profits or maximise expected NPV. Or the decision-maker can create boundary values within which exercise of the option will allow for achieving the set objectives.

5.2. Model Setup

The numerical model for implementing real options on the current case for the African Port is achieved by mathematically translating the conceptual framework. The model is developed assuming that it is in the best interests of the port authority to determine the potential optimal time and magnitude of expansion during the finite project timeline until 2050. The decision strategy for the port authority involves exercising the expansion options in the form of interventions. The decision strategy is intended to maximise the expected net benefits proportionally to the planned capital outlay.

5.2.1. Static NPV

The static DCF model was already in place with the underlying assumptions, forecasts, cash-flow calculations and decision analysis. The necessary information was extracted and the results from the model were further used for comparative analysis.

5.2.2. Estimation of Future Possibilities

Based on the analysis of the current case model (as described in section 4.2), for a particular magnitude of capacity expansion, it is the changes in demand projections that significantly affects the outcome of the DCF financial model. The three scenarios employed in the financial model results in alternative outcomes due to the difference in growth factor used. The future throughput volumes determine the cash flows of OPEX and revenues. Finally, through the exploratory interviews, it was identified that it is demand uncertainty which is influences the port planning process. Considering the observations from the case data analysis and exploratory interviews, it can be claimed that, it is future demand volumes that create uncertainty. This uncertainty influences the financial viability of the project and ultimately affect the project decision.

In the current case study, the cash flows for the project decision are dependent on the future throughput volumes. The conclusions of both exploratory interviews and theoretical background suggest that demand uncertainty is an appropriate variable through which the RO model can be defined. For port expansions specifically, the future net pay-offs and the initial capital outlay is dependent upon a certain expectation of future traffic. Hence, it is proposed, the parameter of “demand” should be used as a base for estimating future possibilities.

- Notations: The uncertainty state variable is the demand which is denoted by V. The demand (or throughput volumes) at time t is denoted by V_t.

- Practical Considerations: The choice of stochastic process to estimate the future possibilities was mentioned to be context-dependent. According to de Magalhães Ozorio et al.(2012), the choice of stochastic process is relevant for real options valuation and influences the the final option value. GBM and MRM have been more commonly used in ROA. As the choice of stochastic processes have great relevance in asset valuation the Unit Root Test or also called as Augmented Dickey-Fuller Test is conducted. This test allows in understanding if the time series is stationary. The Dickey-Fuller tests for unit root which allows determining if the data is random. The test involves applying a regression between historical throughput volumes and lagged historical throughput volumes including a drift which is seen in the below equation:

$$\Delta y = \beta_0 + \beta_1 y_{i-1} + \varepsilon_i \tag{5.1}$$

  where β_1 is the lagged volumes, β_0

  The output of the regression analysis is shown in ... The required parameter for this test is the t-stat value for β_1 which results in -0.45228. For n=12 and $\alpha = 0.05$ the critical value $\tau_c ritical$ for the Augmented Dickey-Fuller Test is -2.61875. In this case $\tau_c ritical$ < $\tau_o bserved$ i.e. -2.61875 < -0.45228. Therefore the null hypothesis cannot be rejected which implies that the time series is not stationary. According to de Magalhães Ozorio et al.(2012) the failure to reject the hypothesis indicates a strong presence of GBM. Additionally, the historical throughput volumes are observed to be random and do not revolve around a mean value.

- Particulars of the Stochastic Process The future throughput volumes is forecasted using a GBM which follows the below equation:

$$dV_t = \mu V_t dt + \sigma V_t dZ \tag{5.2}$$

  where:

  μ = Mean

  σ = Standard Deviation

  dZ = Wiener Increment

  Both μ and σ is obtained from the historical throughput volumes V_t. The shocks or jumps is created by the wiener increment. Peters(2016b) summarises the two properties of wiener increment as follows:

  > *The change in dz within a small interval of dt is $\varepsilon\sqrt{dt}$* where ε is a random draw from a standard normal distribution. The values of dz for any two different short intervals of time dt are independent.

  In Equation 5.2 the first half is called the expectation or trend term and the second half is termed as the variation term. The solution of Equation 5.2 is described and formulated in **??**. The solution for the equation is solved using logarithmic transformation, Ito’s calculus and subsequently using integral calculus. The following equation is a result of the solved solution:

$$V_{t+\Delta t} = V_t e^{(\mu - 0.5\sigma^2)\Delta t + \sigma\varepsilon\sqrt{\Delta t}} \tag{5.3}$$

  where:

  Table 5.1 shows the timing values which were used in the estimation of the stochastic process. The stochastic process was employed for the duration of the forecast period. It is the duration of the historical period through which the parameters of the GBM such as σ^2 and μ were calculated. Finally, the

Table 5.1: Timing Particulars for Estimating Future Possibilities for the case study.

Label	Time	Unit
Start of Historical Period	2005	year
Duration of Historical Period	14	years
End of Historical Period	2018	year
Start of Forecast Period	2019	year
Duration of Forecast Period	32	years
End of Historical Period	2050	year

Augmented Dickey-Fuller test mentioned in the previous paragraph was performed using the historical throughput volumes for the duration of the historical period.

In Equation 5.3, the shocks or the jaggedness to the stochastic process is contributed by ε which is described by a standard normal [N(0,1)]. Monte-Carlo simulations were used to describe uncertainties by randomly picking values for ε within the standard normal distribution.

A total of 2500 runs were simulated for Equation 5.3. A total of 2500 data points were obtained for each year which can be said to qualify as potential throughput volumes at time t for the project duration.

5.2.3. Identification and Operationalization of options thinking

It is the Port Authority of African Port who is the decision-maker and they hold the exclusive option to invest in the expansion project. This step identifies the embedded options within the project and context-based decision trees and decision rules are described within this step.

- **Candidates of Flexibility** The questionnaire from Taneja et al.(2011) was employed to develop a foundation for options thinking.
  - Success Criterion: The success criterion for the expansion project is to accommodate the growing sizes of the vessels and ensure capacity requirements for future activity in the Africa-Asia route. These objectives will help in reducing the congestion which is anticipated at the port. Additionally, aid in rejuvenating the currently ageing infrastructure which will contribute to the economic development of the country.
  - Sources of uncertainty: Future volume projections are the primary source of uncertainty. Second, to this, it is the cash flows of OPEX. OPEX is calculated as a set percentage of revenues; it can be expected that these percentages may vary based on equipment serviceable conditions. However, these variations are difficult to measure with the current information, hence the uncertainty. Thirdly, Madagascar previously has been in periods of financial and political unrest. The chance of recurrence of such strains is not known.
  - Ability to shape this uncertainty: The presence of historical throughput data allows to define the parameters of the stochastic processes. Hence, the primary uncertainty of future volume projection can be fitted and modelled using stochastic processes.
  - Nature of uncertainty: The primary source of uncertainty i.e. demand uncertainty is a market-related risk. It depends upon a variety of exogenous factors such as level of GDP in future, competitive landscape and behaviour, shipping line development (Jansen2014.)
  - Ability to phase the project: The expansion project can be phased based on the magnitude of capacity. The current expansion can be broken down into smaller phases which is contingent on the previous phase's effectiveness. However, the concept of economies might work against the effort to break down the project into smaller phases.
  - Ability to postpone the decision: The decision for the capital outlay can be postponed until there is required serviceability at the port. Therefore, the decision-maker can be said to postpone the decision until the current capacity operates at its upper limit causing congestion and longer waiting times at the port.
  - Presence of contingent decision making: The current project and its underlying financial model do not explicitly consider contingent phases. However, contingent based decision making can be made possible within the current decision plan as it is embedded in the project.

– Flexibility in changing project direction to maximize its value: The current decision and the financial model is structured statically. It is assumed that the complete expansion will take place from 2020 and it will all happen in one go.
– Making the operations or processes flexible: The current expansion plan works with a constant assumption of a capacity utilization rate of 65%. However, it is plausible that by optimising operations the capacity utilization rates can be varied until the upper limit of 75%.
– Decision rule for expansion strategy: The expansion strategy is planned through an expectation of future forecast. The current financial model does not consider any explicit decision rules for the timing of expansions. From the point of view of the port authority, it is the exceedance in capacity and increasing vessel sizes which forms the reasons for expansion.

The current strategy of expansion is that of FQFC (Full Quay Full Crane) which results in a total theoretical capacity of 1450 x1000TEU. As mentioned earlier, there is a possibility to break this project down into several pieces and the expansion can be increased sequential. For this purpose, it was assumed that the project can be broken down into four parts of each 1/4th of the planned capacity[2]. These incremental increase in strategies are the final candidates of flexibility which are embedded in the African Port. Table 5.2 tabulates the existing list of option. Note that, the options ending with the word are the flexible strategies, otherwise they are inflexible strategies of varying magnitude.

Table 5.2: Summary of the Identified Expansion Options which are embedded in the case study.

Option No.	Description	First Moment expansion magnitude (x1000 TEU) [a]	Second Moment expansion magnitude (x1000 TEU) [b]	Total Expansion Magnitude (x1000 TEU) [c] = [a] + [b]	Total Capacity after Expansion (x1000 TEU)	Flexibility Levels
1	HQ	225	-	225	625	0
2	HQHC	525	-	525	925	0
3	FQHC	750	-	750	1150	0
4	FQFC	1050	-	1050	1450	0
5	HQHQHC Flex	225	300	525	925	3
6	HQFQHC Flex	225	525	750	1150	2
7	HQFQFC Flex	225	825	1050	1450	1
8	HQHCFQHC Flex	525	625	750	1150	2
9	HQHCFQFC Flex	525	525	1050	1450	1
10	FQHCFQFC Flex	750	300	1050	1450	1

Figure 5.6 visualises the tree for an inflexible expansion strategy. The inflexible strategy allows the decision-maker to decide to expand at only one time instant t and stay at the same magnitude till the end of the project timeline.

These static options vary from the traditional inflexible strategies in a way that, these options have the option to postpone the investment. Until the moment completion of the expansion, it is assumed that the existing capacity will be optimised for operations. Thereby, increasing the upper limit capacity to 75% of the theoretical capacity, unlike the inflexible options wherein the upper limit capacity is dwarfed at 65% of the theoretical capacity. The flexible strategies on the other hand allow the decision-maker at time t to either choose to expand by moderating the magnitude level of expansion or do nothing. For instance, the flexible strategy tree wherein the first expansion is done by HQ is visualised in Figure 5.7. Further trees for expansion strategies are explained in section 10.3.

[2]This assumption does not consider the technical feasibility of construction of the expansion module. But this research focuses on the benefits and value obtained from the implementation of the ROA model. The case is used as a test bed to present the utility of the conceptual framework and numerical model.

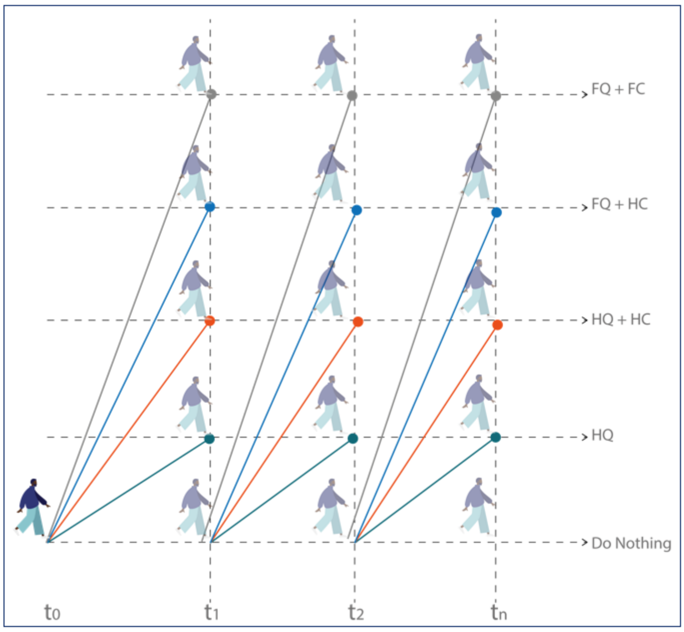


Figure 5.6: Static Option Tree
At a discrete-time t_i the decision-maker has the option to expand by HQ, HQHC, FQHC, FQFC and not expand it further for the rest of the project timeline. The current expansion strategy directly scales to FQFC.

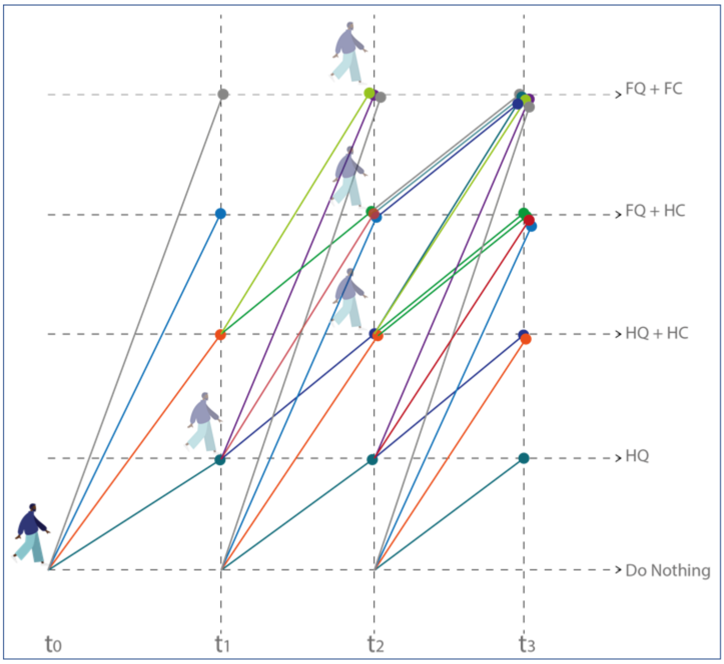


Figure 5.7: HQ Flex Option Tree
At each discrete time t_i the decision-maker has the option to first expand by HQ. At subsequent time moments, the decision-maker can choose to expand by either HQHC, FQHC FQFC or do nothing. Such an expansion structure allows for flexibility on the project.

- **Decision Rules** The results of the future estimation of demand parameter, the objective of the decision rules within the current case study are to identify trigger points. These trigger points can be understood as potential “critical” moments wherein there is a set expectation of capacity exceedance. The capacity exceedance was calculated as real probabilities, unlike the risk-neutral probabilities. An engineering approach argues for real probabilities as the underlying assumptions for no-arbitrage and risk neutrality does not exist de Neufville et al.(2005). However, in the case of the African Port, it has been observed that the decision-maker is influenced by the risk of capacity exceedance. Capacity exceedance could result in additional costs due to congestion and turnaround times. Additionally, there is also a risk that the port might lose its traffic in the future.

– Notations and Considerations: The expansion can take place in a sequential discrete stages of $s \leq 2$ and $s = \mathbb{N}$. The firm has the option to exercise or delay the investment based on the real probabilities. In case on exercising the expansion, based on the option, there is a specific lead time of l where $2 \leq l \leq 8$ and $l = \mathbb{N}$. The triggers are calculated to find the moments wherein expansions can take place. The triggers are implemented through a two-step approach. The first step involves identifying the years wherein the forecasted demand at time t denoted by V_t exceeds the lower operational limit of installed capacity at a set exceedance probability (denoted by X_p). The lower operational limit exceedance acts as a trigger alert for the decision making to exercise an expansion. The equation to calculate the set of triggers is defined by :

$$S_{t1} = \{P[V_t > m_{lli}C_t] \geq X_p\} \forall t, \forall i \tag{5.4}$$

where:

m_{lli} = Lower Limit Multiplier which can take the values of {55%, 65%,70%,75%}

S_{t1} is a vector space and the Equation 5.4 is solved for all values of t and all options mentioned in Table 5.2.

The second step involves identifying the year wherein the forecasted demand at time exceeds the upper operational limit of installed capacity (denoted by X_u) at a set exceedance probability. The upper operational limit exceedance acts as a trigger warning for the capacity expansion to be installed.

$$S_{t2} = \{P[V_t > m_{uli}C_t] \geq X_u\} \forall t, \forall i \tag{5.5}$$

where:

m_{uli} = Upper Limit Multiplier which can take the values of {55%, 65%,70%,75%}

The objective is not for excess capacity, hence, the selected option of expansion is again checked for exceedance S_{t2} is a vector space and the Equation 5.5 is solved for all values of t and all options mentioned in Table 5.2.

– Constraints: The above equations represent the respective time moments where the conditions are fulfilled. The solution set for the potential moments Q_t is created by the following condition:

$$Q_t = S_{t1} \leq t \leq S_{t2} \forall t \tag{5.6}$$

Additionally, while calculating S_{t1} and S_{t2} it must be noted that:

$$m_{uli} \geq m_{uli} + 10$$

This ensures that there is significant difference between the lower and upper limit of capacity utilization.

S_{t1} can be considered as the starting point of investment and S_{t2} can be considered as the last point before which the decision must be taken. Varying Q_t allows for introducing the flexibility to time.

In the case of flexible strategies such as HQHQHC Flex, the expansion is done stages, the above equations allow for calculating the “critical moments” when the current capacity is exceeded. Based on that, the decision-maker has the right but not the obligation to exceed by HQ. It is vital to calculate the critical moments again for the case wherein the summation of current capacity and HQ exceeds the future capacity. The logic and reasoning of these critical moments are similar to what has been described in Equation 5.4 and Equation 5.5. Similar constraints to Equation 5.6 has been applied. Finding these second critical moments denoted by Q_{t2} allows calculating the list of potential moments of reinvestments.

5.2.4. Calculations of Cash flows and Distributions

As mentioned in Figure 4.5, the current financial models the cash-flows under four streams DEVEX, CAPEX, Revenues and OPEX. However, before calculating the cash-flows the assumptions of the model are fixed as follows:

- Assumptions:
  - TEU Factor: Assumed as 1.6.
  - Constrained Forecasts: The constrained forecasts moderates the demand based on supply. Only the demand values which are lesser or equal to the capacity ($V_t \leq X_u$) are considered.
  - Historic share of empty and full containers according to import or export: The historic share of full containers(import) = 78.11%. Historic share of full containers(export) = 21.89%. Historic share of full containers(import) = 1.94%. Historic share of empty containers(export) = 98.06%
  - Timing Assumption: For each value of Q_{t1} and Q_{t2}, the decision maker has the option to simulate the NPV distributions for each option.
  - Escalation Rate: Assumed as 2%p.a.
  - Further assumptions are discussed in the Appendix.
- Cash Flow Calculations:
  - DEVEX: The DEVEX is a fixed cost that is incurred by the port authority for four years. The calculation of DEVEX remains the same regardless of the option in consideration. The DEVEX allows developing expansion plans which can be adapted in real-time. DEVEX is denoted by D.
  - CAPEX: The calculation of CAPEX denoted by I varies based on the option under consideration.

    $$I = K \times C$$

    where:

    K= capacity factor 0.25,0.50,0.75,0.80
    C= Total CAPEX for the project.

    I is analogous to the strike price of financial options.
  - Revenue: The revenue is dependent on the forecasts and the magnitude of the expansion. Revenues consist of concession fees, port dues and cargo dues. The concession fee includes both a fixed and variable component. While port and cargo, dues are variable components. The total revenues earned by the port is calculated as follows:

    $$R_{total} = R_{tc} + R_{cd} + R_{pd}$$

    where:

    R_{total} = Total Revenues (EUR)
    R_{tc} = Total Concession Revenues (EUR)
    R_{cd} = Cargo Dues (EUR)
    R_{pd} = Port Dues (EUR)
  - OPEX: Similar to revenues OPEX varies based on the forecasts and the chosen magnitude of the expansion. The OPEX is calculated as :

    $$O_{total} = G_o + M_o$$

    where:

    O_{total} = Total operational expenditures (EUR)
    G_o = General operational expenditures (EUR) which are calculated as 45.23% of the
    M_o = Maintenance operational expenditures (EUR)

- Discounting: The present value for each of the cash flows is calculated by the use of discounting through WACC. Discounting rate has always been a matter of debate in ROA and varies based on the approach taken. WACC is used due to the use of real probabilities and the non-existence of arbitrage. Additionally, the expansion option is exclusive to the port authority and the port authority evaluates investments related to the African Port. Therefore, the limiting factor of WACC as stated by Myers and Brealey(1995) on WACC does not pose as a limiting factor. The NPV can be calculated using:

$$NPV = \sum_{T=-4}^{T=0}(-D) + \sum_{T=T_{start}}^{T=T_{end}}(-C) + \sum_{T=1}^{T=30}(1 \div (1+WACC))^t \times (-O_{total} + R_{total}) \tag{5.7}$$

The above described process of calculating the distribution values has been repeated for each of the combinations of time moment for each option.

5.2.5. Option Analysis

The resultant distribution and statistical values from the previous step do not result in any actionable results. Therefore for each option, it is proposed that the following analysis is done:

- Analysis to define the possible optimal moments:
  This analysis is used to filter the number of strategies resulting due to the combinations of moments of exercising for each option. Different time moments of expansion can result in different cash-flow streams for the same option. Therefore, this step is focused on filtering the possible potential moments of expansion for each option to its top two or three using the conditions mentioned further. The concept of ROA claims that the call option is valuable when the exercise price is greater than that of the strike price. CAPEX is considered to be the strike price, while the exercise price is said to be the present value of the net pay-offs. According to Meersman, port investments can be evaluated based on the condition of the probability of net pay-offs exceeding the initial capital outlay. This evaluation condition is used for this research, to calculate the probability of such an event occurring. The net pay-offs are represented by E which is calculated as $PV(R_total - O_total_Tax$ and the capital outlay is represented by S is calculated as $PV(D+I)$ which is the summation of the present values of DEVEX and CAPEX. The probability of occurrence of the event wherein net payoffs exceed the initial capital outlays is calculated using the following equation:

$$PV(I) > PV(E) \tag{5.8}$$

  These probabilities are computed for each option at each of the combinations of the time moments.

- Analysis to define the possible optimal magnitude:
  Based on the results of Equation 5.8, the top three or two possible time moments for each of the option is chosen. Maximising the net pay-offs of the decision-maker is one of the objectives. However, it is also to verify whether the complete expansion and flexibility through staging are required. A check on these verification filters leads to the optimal magnitude and the required time of exercising the expansion option. To select the optimal magnitude of expansion the condition of maximised expected NPV values (represented by$MAX(ENPV)$ are compared for all the options.

  To assess the value of flexibility presented by the flexible options, it can be calculated using the following equation:

$$V_{\text{Flexibility}} = MAX\,[0, ENPV_{\text{Flex.}} - ENPV_{\text{Non-Flex}}] \tag{5.9}$$

  In case there is value to the flexibility the above equation will result in a positive number. However, if there is a negative value to the flexibility, it is suggested that the respective flexible option has no value. Hence, an inflexible strategy will be better.

- Analysis for defining the optimal pathway for expansion The above equation will allow filtering the flexible options which have an additional value over the inflexible options. Additionally, the option with the maximum value of flexibility can be selected as the optimal magnitude of the expansion. The corresponding time moments can be considered as the optimal time of exercising the expansion investment.

5.3. Conclusion

The devised conceptual framework builds on the existing ROA approaches for general infrastructural and port infrastructural decision making. The current conceptual framework unravels the mechanics of the option calculation in a transparent manner using tools that are used in practice. The conceptual framework also considers the sources of uncertainty listed by the interviewees and the tools used by them to consider uncertainty.

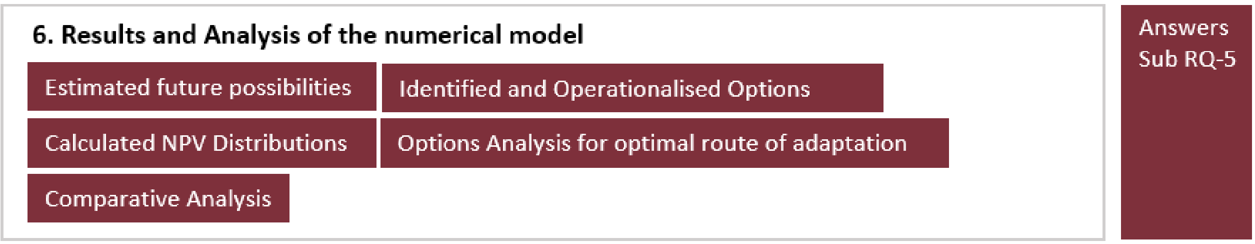
Additionally, the model setup for the case study of African Port also exhibits the applicability of the concept in real-life cases. The design philosophy of the conceptual framework and the numerical model involves asking the questions of: *What the model should do? What insights are required to make a structured decision?*

The results obtained from each step of the numerical model of ROA will be presented in the next chapter.

6

Results and Analysis

Antifragility is beyond resilience or robustness. The resilient resists shocks and stays the same; the antifragile gets better.
— Nassim Nicholas Taleb,



The first half of the chapter describes the step-by-step results of the numerical model for the case of African Port. These results are derived by executing the numerical model on Microsoft Excel. The latter half of the chapter focuses on the analysis of these results(options analysis). In the comparative analysis, insights on the existing DCF financial model for the case study is used. Insights from the case data exploration presented in chapter 4 are utilized for comparative analysis. Based on these analyses the actionable insights for the port authority is explained.

The following are the takeaways from the chapter:

1. Step-by-Step results of the numerical model for the case study.
2. Analysis of options results which allows for determining the value of flexibility. Moreover, based on the objectives of the option analyses, an optimal route for adaptation of expansion for the Port Authority of African Port has been described.
3. Qualitative and Quantitative comparison of static DCF and ROA results based on the case of African Port.

Through the takeaways from the results and the analysis of results the following sub research question has been partially answered:

- **Sub RQ-5**: What can be derived from the comparison of the traditional valuation with the suggested model of real options within the context of the current case of port expansion?

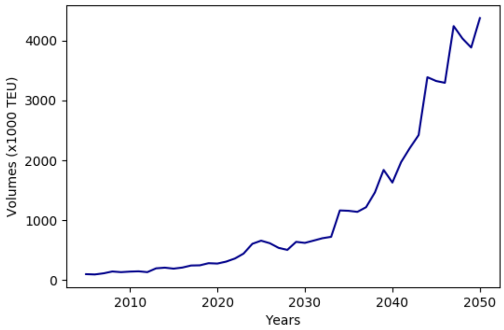
The results and analysis from this chapter will be further utilized in chapter 7 to discuss the implications of these results.

6.1. Results of Case Study Implementations

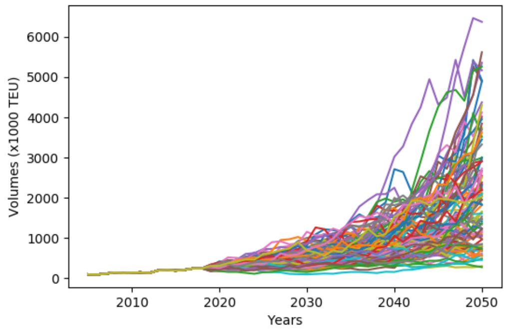
This section explains the results obtained from the application of the numerical model which was devised in section 5.2. The results of Step -1: Static DCF is not explained as it has been described and analysed in section 4.2.

6.1.1. Estimation of Future Possibilities

Based on the historical data from 2005 to 2018 the key parameters for the GBM were calculated. The result of the GBM process for 2019 to 2050 is shown in Figure 6.1a. These forecasts allow for random shocks and do not consider that demand is ever-increasing. The results of the Monte-Carlo simulations for the GBM is shown in figure Figure 6.1b. The 2500 runs allow for 2500 data points every year. This allows calculating further cash flows for a variety of possibilities for demand.



(a) Results of random walk (GBM) process for the forecast period



(b) Results of Monte-Carlo Simulation on the random walk (GBM)

The key statistics for the future throughput volumes is shown in Table 6.1[1]. The statistics for the future throughput volumes thorough GBM and Monte-Carlo simulations are based on 2500 simulations, unlike the three scenarios in the static DCF model. To put into perspective, the forecast volumes from the GBM and Monte-Carlo simulations, the resultant mean forecast volumes is lesser than that of the optimistic and middle forecast for the baseline static DCF model. Therefore, the mean of the simulated future volumes from this step is within the middle and pessimistic range of the forecasts provided in Japan International Cooperation Agency(2015b).

As the timeline progresses the skewness of the simulated forecast volumes is also seen to increase. Therefore, the resultant future volumes of the year in 2045 will be skewed and not behave in a Gaussian way as the forecast volumes for 2020 will behave. Based on the maximum and the minimum value of the forecast, Figure 6.2 visualises the area within which the forecast volumes for each year might lie. In this figure, the area between the maximum and minimum throughput volumes are shown.

Table 6.1: Selected Statistics for the output of GBM and Monte-Carlo Simulations

Description	Unit	Years						
		2020	2025	2030	2035	2040	2045	2050
Mean	000 TEU	283.05	407.64	579.46	829.57	1189.93	1707.65	2451.12
Standard deviation	000 TEU	55.47149	153.6489	297.4355	523.2505	868.9899	1427.304	2331.708
Skewness		0.672176	1.239403	1.957676	2.361349	2.610531	3.062759	3.56396
Kurtosis		0.866589	2.674862	7.813071	10.63388	11.55874	15.54923	21.76814
P25 value	000 TEU	245.1835	298.7077	373.6302	475.7035	632.7487	819.0208	1038.712
P75 value	000 TEU	315.0522	486.3373	708.4563	1029.539	1495.907	2133.254	3039.269

However, the above-visualised demand forecasts are unconstrained. Therefore these demand values are then scaled for the existing capacity. This allows the conversion to the constrained forecasts and only consider the forecast demand which can be served with the installed capacity at the port. Unlike, the static DCF model in the case study, this model allows for dynamic calculation for constrained forecast volumes based on the selected expansion option and expansion time.

[1]The complete statistics for the GBM and Monte-Carlo simulations are tabulated in Table 11.1

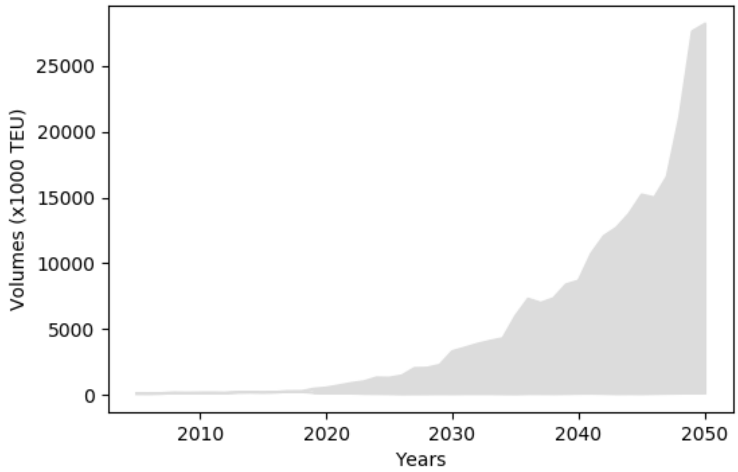


Figure 6.2: Area between the minimum and the maximum value of the randomised future throughput volumes

6.1.2. Identification and Operationalisation of Options

The identified option for the case study is mentioned in the previous chapter in Table 5.2. The identified options work in a two-fold manner. Options numbered from 5-10(mentioned with suffix Flex) are investigated for altering the scale of expansion and sequential stage expansions. Options numbered from 1-5 are solely investigated for the option to postpone the investment. Options numbered from 5-10(mentioned with suffix Flex) are also investigated for the option to postpone the investment. The assumption of postponement of investment involves a focus on optimising operations and delaying the investment. Combining the option to alter scale with the option to postpone allows can allow for a better judgement of optimal time and magnitude of investment.

The 10 expansion options provide the decision-maker with the right but not the obligation to exercise the option at the end of every year until 2045. The decision rules allow for filtering the time moments wherein the forecasted volumes exceed the current capacity. The current decision rules consider that the decision-maker should exercise the expansion from the first moment of lower limit capacity exceedance (55% of the theoretical capacity) with a probability of 70%. And the decision-maker should not delay the investment no more than the first moment wherein the upper limit capacity exceedance (75% of theoretical capacity) has been recorded with a probability of 70%. Using these assumptions Table 6.2, tabulates the potential moments wherein an expansion can be potentially exercised by the port authority.

Table 6.2: Potential moments of exercising the relevant expansion option

Description	Variable Parameters Input			Decision Outputs	
	Exceedance Probability (%)	Lower Limit Capacity Utilization (%)	Upper Limit Capacity Utilization (%)	Potential First Moment(s) of Investment	Potential First Moment(s) of Re-Investment
HQ, HQHC, FQHC, FQFC	70	55	75	2020 - 2023	Not Valid
HQHQHC Flex, HQFQHC Flex, HQFQFC Flex	70	55	75	2020 - 2023	2027 - 2030
HQHCFQHC Flex, HQHCFQFC Flex	70	55	75	2020 - 2023	2039 - 2041
FQHCFQFC Flex	70	55	75	2021 - 2023	exceeds project timeline

Based on the option under consideration, the Figure 6.3 visualises the potential moments wherein the following options can be exercised.

From Figure 6.3 it can be learned that there is a requirement of immediate expansion of the port. However, the option FQHCFQFC Flex involves the second moment of expansion which exceeds the expiration period. Therefore, this option is removed from the list of “to be evaluated options”. Therefore the current list of “to be evaluated options” now has 9 options.

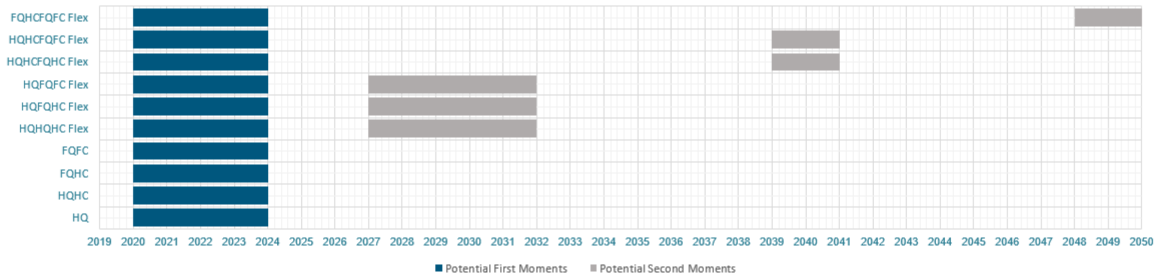


Figure 6.3: Potential first and second moments of investments for the respective options

6.1.3. Calculation of NPV Distributions

The results from the previous step indicate the valid potential combinations. Based on these potential moments, the cash flows have been computed. A total of 100 combinations of potential moments are calculated in total for the relevant options. These 100 combinations of potential moments result in 100 distributions of NPV for a total of 9 valid options. The P25, Mean, P50 and P75 values are computed from these distributions. For instance, the option of HQHQHC Flex Figure 6.4 visualises the tables showing the mentioned statistics for the combination of potential moments.

Mean		Second Moment of Investment			
		2,027	2,028	2,029	2,030
First Moment of Investment	2,020	30,469	28,345	25,942	22,853
	2,021	28,594	26,457	24,040	20,934
	2,022	27,267	25,129	22,710	19,601
	2,023	25,980	23,841	21,421	18,308
	2,024	24,080	21,940	19,519	16,402

P50		Second Moment of Investment			
		2,027	2,028	2,029	2,030
First Moment of Investment	2,020	57,826	56,456	53,954	50,199
	2,021	56,289	54,843	52,267	48,930
	2,022	55,304	53,342	51,187	47,500
	2,023	53,832	52,016	49,700	46,067
	2,024	51,643	49,756	47,706	43,802

P25		Second Moment of Investment			
		2,027	2,028	2,029	2,030
First Moment of Investment	2,020	(6,750)	(6,191)	(6,159)	(5,868)
	2,021	(7,614)	(7,829)	(7,496)	(7,154)
	2,022	(8,255)	(8,499)	(7,933)	(7,553)
	2,023	(8,842)	(8,626)	(8,541)	(8,069)
	2,024	(9,884)	(9,386)	(9,309)	(8,832)

P75		Second Moment of Investment			
		2,027	2,028	2,029	2,030
First Moment of Investment	2,020	80,688	76,236	71,113	64,892
	2,021	78,050	73,294	67,900	61,859
	2,022	75,907	70,918	65,679	59,470
	2,023	73,998	68,820	63,461	57,426
	2,024	71,483	66,271	60,907	54,803

Figure 6.4: Relevant statistics figures for the NPV distributions for HQHQHC Flex Option

Similar visualisations are extracted for each of the 9 options and have been visualized in chapter 11.

The mean, P50 and P75 values are observed to reduce as the investment is postponed. Additionally, these results indicate that lower capital outlays result in a positive NPV. However, judging by the Mean NPV value result in ignorance of the extreme values. The drawbacks of a DCF model is claimed to be the use of single-point estimates of mean values without considering the different values the NPV parameter may take (Triantis,2005). Additionally holding the rule of positive NPV strictly will result in a smaller expansion. This smaller expansion may not achieve the objectives of the decision-maker in terms of strategic outlook and the requirement of gaining more market share.

Therefore the option of HQ is not considered further as this lower scale of expansion will only result in a nominal expansion of the port and results in lower revenues when compared to the other options. Therefore the current list of “to be evaluated options” now has 8 options.

6.1.4. Option Analysis

The resultant distributions for the 8 options present a total of 96 strategies. The options analysis involves comparing options to calculate an approximate optimal moment and optimal magnitude of investment. Additionally, flexible expansion options are evaluated for their value of flexibility.

Analysis within options for optimal time

One of the baseline rules for ROA has been to exercise the investment in the case wherein the exercise price is greater than that of the strike price. Using equation Equation 6.1 the probability of such an event occurring has been calculated for each option at each of the time moment.

$$PV(I) > PV(E) \tag{6.1}$$

These probability values have been tabulated and described in two subsections of static options and flexible options.

1. Expansion by static options with the provision to postpone the investment

   Table 6.3 tabulates the Mean NPV and probability of pay-offs exceeding the initial capital outlays for the static options of HQHC, FQHC and FQFC.

Table 6.3: Probability that pay-offs exceed initial capital outlays for all the static options optimised for operations

Description	Selected Time Moments			
	2020	**2021**	**2022**	**2023**
HQHC (After Expansion magnitude: 9,25,000 TEU)				
Mean	35.507	32.79888	29.42143	27.03998
P(E>S)	0.727491	0.726181	0.7204	0.7208
FQHC (After Expansion magnitude: 11,50,000 TEU)				
Mean	-17.4919	-21.8289	-25.4275	-29.4275
P(E>S)	0.531813	0.520016	0.5113	0.5103
FQFC (After Expansion magnitude: 14,50,000 TEU)				
Mean	-57.9216	-63.0852	-66.6837	-62.1795
P(E>S)	0.446979	0.438751	0.4316	0.4512

   Comparing all the results, it has been observed that, it is the option of HQHC which has the maximum probability of the net revenues exceeding the initial capital outlays. Assessment by the polarity of Mean NPV value will recommend choosing HQHC. Moreover, if the assessment is done using maximum Mean NPV value for each option then, the option with earlier exercise moments will be chosen. However, for FQFC the maximum probability of payoffs exceeding the initial capital outlays occurs in the last time moment of 2023. Therefore, this provides a first-hand example of the drawback of assessing by just the maximised Mean NPV value of the option. From these results, the top-two alternatives for each option are carried forward to assess its performance against other flexible options.

2. Expansion by flexible options in terms of scale and time The following flexible strategies have two starting points of expansion. The first is to expand by HQ (225 x1000TEU) and then the subsequent expansions take place. while the second is to expand by HQHC (525 x1000TEU).

   - Expansion by HQ as the first step of expansion
     Table 6.4 tabulates and compares the probabilities of payoffs exceeding the initial capital outlays. This table only tabulates options wherein the first stage of expansion was done by HQ and subsequently expanded by HQHC, FQHC or FQFC resulting in a total capacity of 925, 1150 and 1450 x1000TEU respectively.

Table 6.4: Comparison of P(E>S) for the options wherein the first stage of expansion was done through HQ

Description	**Selected Time Moments**															
	2020 & 2027	**2020 & 2028**	**2020 & 2029**	**2020 & 2030**	**2021 & 2027**	**2021 & 2028**	**2021 & 2029**	**2021 & 2030**	**2022 & 2027**	**2022 & 2028**	**2022 & 2029**	**2022 & 2030**	**2023 & 2027**	**2023 & 2028**	**2023 & 2029**	**2023 & 2030**
HQHQHC Flex (Total magnitude after expansion: 925 TEU)																
P(E>S)	0.7332	0.7356	0.7376	0.7384	0.732	0.734	0.7348	0.7364	0.7328	0.7336	0.734	0.734	0.7328	0.7332	0.7328	0.7328
HQFQHC Flex (Total magnitude after expansion: 1150 TEU)																
P(E>S)	0.5136	0.5064	0.4952	0.4704	0.506	0.498	0.4852	0.4564	0.5	0.4924	0.4792	0.446	0.496	0.4868	0.472	0.4324
HQFQFC Flex (Total magnitude after expansion: 1450 TEU)																
P(E>S)	0.4392	0.4368	0.4356	NA	0.432	0.4328	0.4284	NA	0.428	0.4292	0.4256	NA	0.428	0.4244	0.422	NA

     The probability that the payoffs exceed the initial capital outlay is highest for the option of HQHQHC Flex which is then followed by the option of HQFQHC Flex and finally HQFQFC Flex. HQHQHC Flex involves the least expansion magnitude in comparison to the other options. Due to this, this option involves the least capital outlay in comparison to the other two options. However, there is a deeper requirement of analysis in terms of whether the extra capacity provided by HQFQHC Flex and HQFCFC Flex is required in the project timeline. The top three alternatives are chosen from these three alternatives to compare against other options to verify the requirement of the additional capacity.

The top three-timing alternatives are chosen from the three options for comparing against other options and inflexible expansion strategy.

- Expansion by HQHC as the first step of expansion
  Table 6.5 tabulates and compares the probabilities computed through Equation 5.8. This table only tabulates options wherein the first stage of expansion was done by HQHC and subsequently expanded by FQHC or FQFC resulting in a total capacity of 1150 and 1450 x1000TEU respectively.

Table 6.5: Comparison of P(E>S) for the options wherein the first stage of expansion was done through HQHC

Description	Selected Time Moments															
	2020 & 2039	2020 & 2040	2020 & 2041	2020 & 2042	2021 & 2039	2021 & 2040	2021 & 2041	2021 & 2042	2022 & 2039	2022 & 2040	2022 & 2041	2022 & 2042	2022 & 2039	2023 & 2040	2023 & 2041	2023 & 2042
HQHCFQFC Flex (Expansion magnitude: 1450TEU)																
Mean (Million EUR)	-91.499	-94.5091	-97.7901	-101.344	-95.85	-98.8629	-102.146	-105.709	-99.3119	-102.33	-105.624	-109.183	-99.3119	-105.209	-108.512	-112.067
P(E>S)	0.2704	0.222089	0.1804	0.1472	0.230892	0.1844	0.1532	0.1236	0.1972	0.1616	0.132	0.106	0.1972	0.1616	0.132	0.106
HQHCFQHC Flex (Expansion magnitude: 1150 TEU)																
P(E>S)	0.5008	0.494198	0.488	0.4784	0.482193	0.48	0.472	0.4656	0.4724	0.464	0.4568	0.446	0.4724	0.464	0.4568	0.446

In this comparison too, it can be observed that the pay-offs exceed the initial capital outlay for the lower capacity expansions. Additional, assessment through maximisation of mean NPV ignores the potential of the expansion options which can be executed later. Mean NPV are indicated to be prone to error in case of range numbers consisting of high variation. The top three alternatives are chosen from these three options to compare against other options to verify the requirement of the additional capacity.

In both these cases wherein there is an option to alter the scale of investment, it has been observed the expansion through a lower capacity allows for a greater chance for the pay-offs to exceed the initial capital outlay. Additionally, another pattern has also been observed based on the comparison of Mean NPV Values wherein delaying the initial capital outlay till the last moment results in lesser pay-offs than the exercising at the first moment. For instance, for the fixed considered timeline, if the option to expand is exercised in 2035, there are close to 10 - 12 years to benefit from the greater revenues. On the other hand, if the option is exercised in 2027 then there are close to 20 years to earn the revenues from the expansion. However, this does not indicate that late exercise of the options is not desirable. However, delaying the investment later in the timeline also comes with a cost of an escalating factor on CAPEX. Moreover, delaying the time for expansion also reduces the time for generating revenues within the considered project timeline.

Analysis within options for optimal magnitude

In this subsection, the top two or three alternatives from the previous steps are used as input. A total of 20 strategies have used an input for comparison and evaluation of their respective Expected Net Present Value (ENPV) values. The mean ENPV is calculated using the cumulative distribution plots. Table 6.6, tabulates the of Mean ENPV for each option.

Table 6.6: Comparison of Expected NPV values within options

Description	Magnitude of Expansion (X1000 TEU)	First Moment of expansion	Second Moment of expansion	Mean NPV (Million EUR)	Probability of Mean Value Occurrence	ENPV (Million EUR)	Max(ENPV) for similar magnitudes of expansion (Million EUR)	Max(ENPV) regardless of the magnitude of expansion (Million EUR)
HQHQHC Flex	525	2020	2029	25.772	0.3535	9.112	9.112	9.112
		2020	2030	22.686	0.341373	7.744		
HQHC		2020	NA	23.507	0.35679	8.3871		
		2021	NA	20.7988	0.3469	7.215104		
FQHC	750	2020	NA	-17.4915	0.52546	-9.19108359	-9.19108	
HQFQHC Flex		2020	2027	-28.7283	0.39833	-11.44334374		
		2021	2027	-31.3533	0.390929	-12.25691422		
HQHCFQHC Flex		2020	2039	-30.6757	0.39046	-11.97763382		
		2020	2040	-31.4566	0.38795	-12.20358797		
FQFC	1050	2021	NA	-57.9216	0.4505687	-26.09766001	-26.0977	
HQFQFC Flex		2020	2027	-66.55	0.446896	-29.7409288		
		2020	2028	-69.85	0.441449	-30.83521265		
HQHCFQFC Flex		2020	2039	-91.499	0.393733	-36.02617577		
		2020	2040	-94.5103	0.3866107	-36.53869324		

It is the options of HQHQHC Flex that presents the Max(ENPV) value in comparison to all the other values. Additionally, the ENPV values are observed to reduce as the magnitude of expansion increases. This is a pattern that has been several times observed. However, a closer look at the decision rules suggests that, after the expansion by 525 x1000TEU, the capacity will only exceed in the years between 2039 - 2042. Note these time moments are well at the end of the project timeline. Therefore, the business case of expanding the port further than 525 x1000TEU is not required from a supply perspective. If an investment is made to expand in the time moments between 2039 - 2042, there will too little time to generate adequate pay-offs. Additionally, there is a specific lead time associated, therefore exercising an option in 2039, will only be operational in 2040 (differs based on the exercised option). These reasons collectively increase the attractiveness of expanding the capacity by 525 x1000TEU.

The operational capacity after expanding by 750 x1000TEU is sufficient for handling the demand until the end of the project timeline for the case. The interesting observation in the case of these flexible strategies is that, the moments of expansion does not lead to large deviations of ENPV. For instance, in the case of HQFQHC Flex, if in the year 2020 the expansion is made by HQ(225 x1000TEU) followed by 525 x1000TEU in 2027, then the ENPV is observed as -11.44 Million EUR. While in the case of HQHCFQHC Flex, if in the year 2020 the expansion is made by HQHC(525 x1000TEU) followed by 225 x1000TEU in 2039 then the ENPV is observed as -11.98 Million EUR. The comparison of these options results in the options HQFQHC Flex exceeding the option of HQHCFQHC Flex only by 0.46 Million EUR. This implies that, the decision-maker can benefit by waiting until 2039 with a cost premium of 0.46 Million EUR. This example displays, the advantage that the decision-maker gains by waiting.

Expansion by 1050 x1000TEU is the least attractive magnitude of the expansion. Unlike, the previous expansion strategies, the option of waiting and delaying do not prove to provide a competitive strategy. Waiting to reinvest until 2039 will result in a loss of 6 Million EUR than reinvesting in 2027. This expansion magnitude is the highest in terms of magnitude and also involves large CAPEX. Additionally, waiting until 2039 also shows that potential revenues can be lost during the period of delay.

In summary, based on the comparison of Max(ENPV) values it is the flexible expansion option of HQHQHC Flex wherein the first investment is made in 2020 and the re-investment is made in 2029 which proves to be optimal. The optimal path of adaptation for the expansion strategy has been visualised in Figure 6.5.

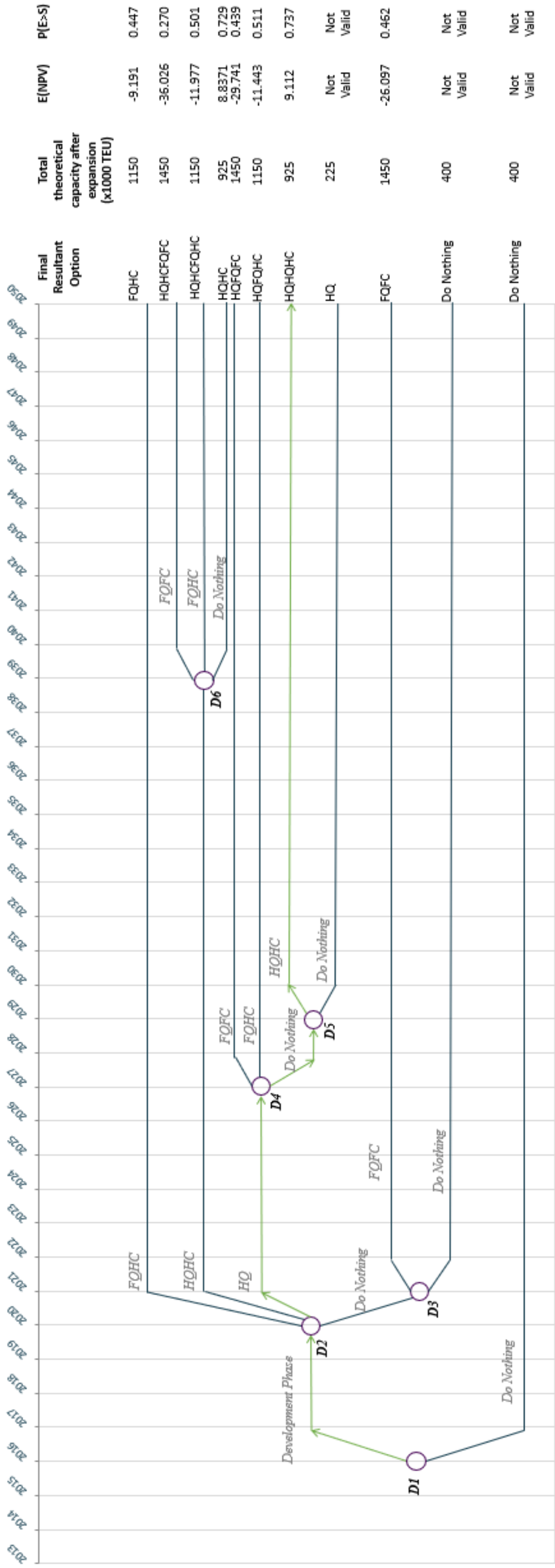


Figure 6.5: Optimal adaptation strategy for Port Authority

The tree depicts the expected optimal moments wherein the port authority should make the decision to expand. Based on the maximisation of expected value of NPV, the optimal route for expansion has been selected to HQHQHC. However, the tree provides with other alternative routes with their respective expected NPV.

6.1.5. Analysis for Flexibility

Analysis for flexibility can also be dubbed as a form of comparative analysis wherein the flexible expansion strategies are compared to the inflexible strategies. The value of flexibility is calculated by the following equation:

$$V_{\text{Flexibility}} = MAX\,[0, ENPV_{\text{Flex}} - ENPV_{\text{Non-Flex}}] \tag{6.2}$$

The current financial model developed by Royal HaskoningDHV involves the NPV value for FQFC (expansion magnitude of 1050,000TEU with a construction start date of 2020). It must be realised that, the outcome of the DCF model is a single point estimate value. On the other hand, the outcome of the numerical model of ROA is an expectation value of NPV. ENPV is a product of NPV and the probability of occurrence. Therefore, to calculate the value of flexibility, the inflexible strategy from the static DCF model, the outcome NPV needs to be converted into ENPV by running the numerical model of ROA (but keeping the timing assumptions of the static DCF model intact). The values of flexibility are for each expansion strategy has been tabulated in Table 6.7.

Table 6.7: Analysis on options for quantifying value of flexibility

The table presents the value of flexibility by comparing flexible expansion strategy against inflexible strategies. These flexible strategies are expected to follow a multi-stage sequential installation of capacity. On the other hand, the inflexible strategies are expected to follow a single stage complete installation of respective capacity.

Description	Total Magnitude of Expansion (x1000 TEU)	First Moment of Expansion	Second Moment of Expansion	ENPV	Value of Flexibility (inflexible - flexible) Million EUR
HQHQHC Flex	525	2020	2029	9.112	0.74525
HQHC Inflexibe		2020	Not Valid	8.366	0
HQFQHC Flex	750	2020	2027	-11.44334	1.86815626
HQHCFQHC Flex		2020	2039	-11.97763	1.33386618
FQHC Inflexible		2020	Not Valid	-13.3115	0
HQFQFC Flex	1050	2020	2027	-29.74093	0
HQHCFQFC Flex		2020	2039	-36.02618	0
FQFC Inflexible		2020	Not Valid	-26.17541	0

The optimal path of adaptation using the option of HQHQHC Flex has the flexibility value of 0.74525 Million EUR. However, the option with the highest value of flexibility is HQFQHC Flex with a flexibility value of 1.868 Million EUR. This does not imply that the optimal adaptation strategy is inefficient.

Both these options of HQHQHC Flex and HQFQHC Flex consists of the first stage of expansion by HQ (225 x1000TEU). If the port authority anticipates more demand in the short-term future, they can expand by the FQHC component during the decision moment in 2027. However, if they want to exercise caution and delay capital outlays for the higher expansion magnitude, then they can expand by HQHC component during the decision moment at 2029. Therefore, the use of these options allows the decision-maker to adapt their decisions based on the real-time market conditions.

6.1.6. Takeaways for the Port Authority

Based on the results and analysis the insights for the Port Authorities are explained in this subsection. Table 6.8 tabulates the relevant takeaways which are explained in the following points:

Table 6.8: Optimal times and magnitudes of Expansion for each flexible option which is relevant for the Port Authority of Toasmasina

Option	Total Magnitude of Expansion [x1000 TEU]	Expansion magnitude at the first moment of expansion [x1000 TEU]	Expansion magnitude at the second moment of expansion [x1000 TEU]	First moment of Expansion [a]	Second Moment of Expansion [b]	Number of years between the stages [b]-[a]	ENPV [Million EUR]
HQHQHC Flex	525	225	300	2020	2029	9	9.112
HQFQHC Flex	750	225	525	2020	2027	7	-11.443
HQFQFC Flex	1050	225	725	2020	2027	7	-29.740
HQHCFQHC Flex	750	525	225	2020	2039	19	-11.977
HQHCFQFC Flex	1050	525	525	2020	2039	19	-36.026

1. *How much capacity will be required? What should be the magnitude of expansion?*

   The current decision to expand by 1050,000TEU is not necessary based on the simulated future throughput volumes. Expansion by 525,000TEU will be enough to handle the simulated throughput volumes until 2041. Therefore, expansion by such a capacity will experience congestion only in the last 10 years of the project timeline. On the other hand, the decision to expand by 750,000TEU will be enough to handle the simulated throughput volumes until 2050. The proposed optimal adaptation strategy is that of HQHQHC Flex wherein the total magnitude of expansion is 525,000TEU. If the congestion at the port following 2041 is leading to inefficiencies, then the port authorities have the option to increase the utilization rate. This will ensure that the throughput volumes in the last 10 years can be handled. However, these points are based on the information available in the present. If the market conditions improve or deteriorate the port authority can adapt the proposed strategy. Therefore, expansion by a total magnitude of 525,0000 TEU in two steps of expansion is proposed.

2. *When to expand?*

   Based on the analysis of the flexible strategies, the port authorities should exercise the first option to expand in 2020. For the proposed optimal strategy, the port authority can exercise their option to expand by HQ(225,000TEU). The next decision moment wherein the port authority can take the option to expand is the year 2029. Here the port authority is suggested to expand by a further of 525,000TEU. Information on the time to expand for other strategies is tabulated in Table 6.8.

3. *Until when the decision can be postponed?*

   In the case of the proposed optimal strategy, the port authority can postpone the second expansion module until the beginning of 2029. In these 8 years, the port authorities can verify their next step of investment. At this decision moment of 2029, the port authority can choose to expand by the proposed strategy or can also alter their scale of expansion. Information on the time available to postpone the second expansion module is tabulated in Table 6.8.

4. What is the position of such an investment? In the case of the proposed optimal strategy, the ENPV is 9.112 Million EUR with a value of flexibility of 0.74525 Million EUR. The comparison of this ENPV against the existing strategy of the port authority shows that the port authority can save 17.063 Million EUR. Therefore, the current port expansion plan adopted by the port authority of installing 1050,000 TEU does not pose a benefit in terms of the project outcome.

Table 6.9: Qualitative Comparison between static DCF and numerical model of ROA

Parameters	DCF	ROA model	Remarks
Forecasts	Constant percentage based increment	Based on stochastic process of GBM	Consideration of GBM allows for modeling the volatility and accounting for the shocks in the throughput volumes.
Scenarios	Three scenarios based on different growth percentages.	Monte-Carlo Simulations for the stochastic process for 2500 runs	The three scenarios involve three different growth percentages. However, through Monte-Carlo simulations 2500 random possibilities of volumes can be calculated for each year.
Consideration of Strategies	Inflexible	Both inflexible and flexible	Allows for options thinking and operationalising options of staged market entry and option of postponement. These options can be also engineered in the existing DCF model. But, ROA allows for formal consideration of these options which can be used in the further probabilistic evaluation.
Expansion Plan	NA	Determinant on capacity exceedance calculated using probabilities	The expansion plan in the existing DCF model is not modelled using decision rules. The ROA model allows for exercising a particular expansion option based on its probabilities of capacity exceedance. This allows for creating a multi-stage sequential expansion wherein the focus is maintained on the potential demand(contrasting to excess demand).
Evaluation Metrics during the feasibility stages	1. NPV 2. IRR 3. Payback Period	1. Probability of net revenues exceeding initial capital outlays, 2. Expected NPV 3. Value of flexibility	From a deterministic evaluation of metrics the decision-maker only understands the financial viability of the strategy. But through ROA, the decision-maker can get an overview of the probability of the NPV value occurring. Additionally, a monetary value for flexibility can be calculated, which allows for substantiating for using options based expansion. The decision maker can also identify options and moments of investment wherein, there is a probability of net revenue exceeding the capital outlays. therefore, the evaluation is not only based on the polarity of NPV. Rather it is based on success probabilities and monetary value of flexibility.

6.2. Detailed Comparative Analysis

This section provides a summary of the comparison between the results obtained from a static DCF model and the numerical model of ROA for the case of African Port. Table 6.9 tabulates the qualitative comparison of the key differences between the static DCF and the ROA model for the African Port. These remarks mentioned in the table also presents the qualitative benefits which are derived from the application of the proposed ROA model for the case. These qualitative differences can be generalised to other brownfield projects wherein the proposed ROA model is applied.

The quantitative comparison of the results between the static DCF model and a ROA model is tabulated in Table 6.10. This quantitative comparison is specific to the African Port. The insights derived from the comparison is also mentioned in the table. These remarks also present the quantitative benefit which is derived from the application of the proposed ROA model for the case.

Table 6.10: Quantitative Comparison between static DCF and numerical model of ROA

Parameter	DCF	ROA model [Flexible Strategies]	Remarks
Number of flexible levels available for expansions	0	4	The current DCF model only considers inflexible strategies. The current ROA model allows for multi-stage sequential expansions with four expansion modules.
Comparison of Expected NPV (in Million EUR)			
Expected NPV when the total expansion magnitude is 525,000 TEU	8.336	9.112	0.776 Million EUR will be saved by the port authority if the port authority models the expansion strategy based on flexibility.
Expected NPV when the total expansion magnitude is 750,000 TEU	-13.3115	-11.44334	1.86816 Million EUR will be saved by the port authority if the port authority models the expansion strategy based on flexibility.
Expected NPV when the total expansion magnitude is 1050,000 TEU	-26.17541	-29.74093	The static expansion yields a higher ENPV in comparison to the ROA model. Instilling flexibility in such magnitude of expansion will result in losses for the port authority. For this case, it is better to execute a single-stage complete expansion by the said capacity.
Comparison of value of flexibility (in Million EUR)			
When the total expansion magnitude is 525,000 TEU	0	0.776	The monetary benefit which can be gained through adding flexibility amounts to 0.776 Million EUR.
When the total expansion magnitude is 750,000 TEU	0	1.86816	The monetary benefit which can be gained through adding flexibility amounts to 1.86816 Million EUR.
When the total expansion magnitude is 1050,000 TEU	0	0	There is no monetary benefit by using flexible strategies.
Comparison of start time of construction			
When the total expansion magnitude is 525,000 TEU	2020	2020 and 2029	ROA allows for breaking the construction of the expansion plan in stages. For this case, the port authority can choose to wait and see until the end of 2026 and 2028. Hence, does not fall into the trap of considering a set expansion date for the complete expansion.
When the total expansion magnitude is 750,000 TEU	2020	2020 and 2027	
When the total expansion magnitude is 1050,000 TEU	2020	2020 and 2027	

6.3. Conclusion

Through the application of the numerical model for the case of African Port, a total resultant of 100 NPV distributions were obtained. A total of 10 expansion options were derived from the embedded case study. There were a total of 96 strategies as input for the options analysis phase. With the use of objectives of maximising the probabilities of net payoffs exceeding the initial capital outlay, these 96 strategies were filtered for optimal moments of exercising. A total of 20 combinations of time and magnitude of expansion was the output from this objective which are visualised for in Figure 6.6.

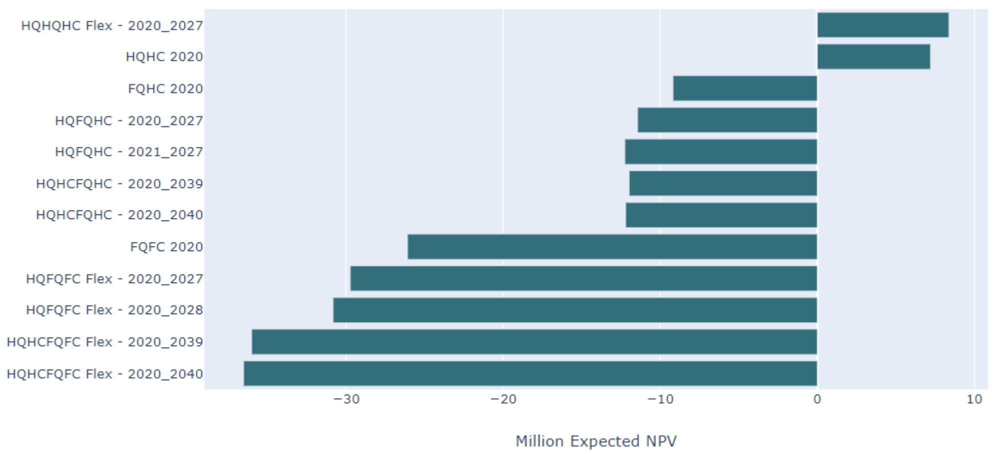


Figure 6.6: Comparison of Options for their respective expected values of NPV

The use of the objective of maximising expected NPV for each option allows finding the optimal time and magnitude for the relevant option. This option is called the strategy of adaptation which the port authorities can pursue. This strategy of HQHQHC (2020,2027 total expansion magnitude 525,000TEU) has been visualised in Figure 6.5. The flexible strategies are analysed for the monetary value presented by these options. It is only the options of HQHQHC Flex, HQFQHC Flex and HQFCFQFC Flex which have the value of flexibility. It is only in these cases wherein staging results in a monetary benefit. The flexibility of each of the considered options has been visualised in Figure 6.7.

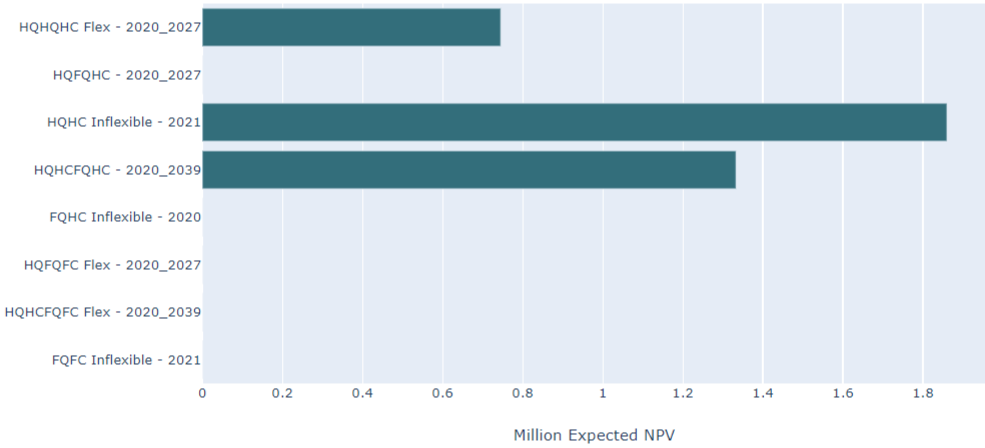


Figure 6.7: Comparison of options for their value of flexibility

Based on the current availability of data and subject to the assumptions, it is advised that the African Port scales its investment with a lesser aggressive strategy. If HQHQHCFlex (theoretical capacity after expansion: 925'000 TEU) seems too conservative, then it is proposed that the port authority could expand with the option HQFQHCFlex (theoretical capacity after expansion: 1050'000 TEU). It can be claimed that the first expansion by HQ (225'000TEU) allows for switching between future subsequent expansions. Static options which can be only optimised for operations present an additional utility. The static options which are optimised for operations show greater expected NPV values than that of all the flexible strategies (except for HQHQHC). This implies that more than staging it is the optimisation of operations that present a utility in this case. Another argument for a static option with optimisation of operations, allows the port authority to wait and observe, the changes in markets, technology or environmental regulations.

The comparison between the static DCF model and the numerical model shows that through the ROA model flexibility can be monetised. Moreover, through the expansion options, the ROA model provides for select growth pathways that can be adapted based on new information. The comparison of ENPV of the proposed adaptation strategy against the current strategy adopted, suggests a saving of 17.06 Million EUR. Comparison of the adopted flexible strategy of expansion magnitude 525,000TEU against the inflexible strategy of similar expansions strategy presents a saving of 0.776 Million EUR. Through ROA a shift to the probabilistic calculation can be made wherein the impacts of postponing or altering the scale of the investment can be studied.

The results and the analysis obtained from the numerical model will be discussed in the next chapter.

7
Discussion

Uncertainty is the only certainty there is, and knowing how to live with insecurity is the only security.
— John Allen Paulos

7. Discussion		Answers Sub RQ-5
On Conceptual Framework	On Option Mechanics and Results	
Validation of Research	Implications on Scientific and Practical Relevance	
On Aspects of Generalization and Usability		

This chapter extends the results and analysis from chapter 6 to a dialogue presenting the meaning and relevance of the results. This is done at five levels, on the conceptual framework level, on the options results and mechanics, validation of the research, implications on scientific relevance and finally the usability and generalizability. To discuss the conceptual framework the appropriate takeaways on the devised conceptual framework from chapter 5 are used. To discuss the option results and mechanics, takeaways on the analysis of options results from chapter 6 are utilized. The validation of the research presents the perspective of experts on the devised conceptual framework, results and broader implications of ROA. Finally, to discuss the usability and generalizability of the model, the takeaways from the validation interviews and the insights from the exploratory interviews mentioned in chap:ExplorationandIdeationcontent are employed.

Through the takeaways from the discussion on option results and option mechanics, this chapter, allows for partially answering the following research question:

- **Sub RQ-5**: What can be derived from the comparison of the traditional valuation with the suggested model of real options within the context of the current case of port expansion?

7.1. On Conceptual framework

The current conceptual framework is devised based on previous ROA applications in infrastructural applications. Additionally, exploratory interviews allowed for understanding the characteristics of the port decision-making process. This was vital to contextualise the theoretical approaches ROA to the realities of the practice. Unlike Reyes et al.(2019) and Lagoudis et al.(2014), the conceptual framework is not a direct extrapolation of past approaches. The conceptual framework reasoned the existing approaches and verified whether these assumptions are valid for port infrastructural decision making. The following points presents the added value of the framework over previous ROA implementations:

- Borison(2003) critiques that, the works of ROA considers a random walk process without providing enough verification for the use of such a statistical process. In the devised conceptual framework, an Augmented Dickey-Fuller test is suggested for the verification of the stochastic process. However, there can be other tests that present greater utility. However, deeper investigation into such tests was considered as out of scope for this research.

- Triantis(2005), critiques that, application of ROA do not mention the underlying assumptions with clarity. However, in the mentioned conceptual framework, there are arguments for using such an approach. There is clarity especially, around the use of probability calculations, use of discount rates, decision rules and cash flow calculations.
- The devised conceptual framework provides the flexibility to combine uncertainties and include further solution algorithms for options analysis. The step-5 of the conceptual framework can be defined by the user to analyse the results of the option based on their objective. One of the key limitations highlighted by Machiels et al.(2021) corresponds to the limited analysis of options. It is the value of the flexibility that is presented as the analysis. For instance, in the case study implementations, the effect of varying time and magnitude was also studied on the output cash flow distributions.
- Finally, the conceptual framework is devised using practitioner's tools of scenario analysis, probabilistic calculation and Monte-Carlo approaches using a spreadsheet approach in Microsoft Excel. This can be said to allow for more acceptance by the practitioners. Additionally, the numerical solution allows for finding the approximate solution for real-life problems

7.2. On Option Results and Mechanics

Machiels et al.(2021) and Borison(2003) mention that many applications do not discuss the implications of option values. It has been especially claimed by Machiels et al.(2021), articles focus on providing maximum ENPV values and do not present the different implications which can be derived from the ROA implementations. Through the following points the implications of options results are highlighted:

1. **Real Options Analysis is not focused on creating accurate estimates of forecasts rather it provides different paths of adaptation**
   The results suggest that the objective of GBM and Monte-Carlo analysis is not to develop accurate forecasts. Rather it is to account for numerous growth and decline paths. These paths allow for considering the volatility of the uncertainty parameter. Similar to the conclusions of, Mittal(2004), ROA implementation for the case study allowed for adapting the expansion strategy based on several upwards and downwards movement of the demand parameter.

2. **Positive NPV is not an indication of a reasonable investment**
   In the current case study, a positive ENPV occurs if the port authority expands by 0.25 or 0.5 times the planned capacity. At other moments the ENPV has been observed to be negative. There could be two reasons for the negative ENPV. Either the said expansion is not required or the capital outlay is too high that the project timeline is too short for obtaining the required pay-offs. In this case study, both of these reasons are valid. The CAPEX for the planned expansion of 1450 x1000TEU amounts to 350 million which is a large upfront capital and the operational timeline does not provide enough time for a resultant positive NPV.

   If the rule for evaluating an investment is based on the polarity of NPV, then in that case it is the expansion by HQ which allows for achieving that objective. However, an expansion by HQ results in deficient capacity by the year 2032. Therefore, from 2032 onwards the port authority will lose the potential revenues which could have been earned if the expansion was done with a greater capacity. Hence, evaluation of results by the polarity of ENPV might lead to insufficient conclusions. The downsides of evaluating port expansion investments with polarity of NPV has been extensively discussed by Meersman and Van de Voorde(2014), Meersman(2005) and Balliauw(2020). Therefore, in magnitude decision problems, smaller magnitudes of expansion will present a higher utility in terms of the polarity of NPV.

3. **If the lead time is higher it is beneficial to install earlier**
   Options with a longer lead time are observed to become less attractive when the expansion is delayed. It can be claimed that expansion done during lesser congestion is better than doing when there is more congestion. This argument is in line with the findings of Aguerrevere(2003). According to the author, expansion involving a longer time for construction within a congested facility will result in inefficiencies in operation. These inefficiencies could result in loss of revenues and overruns in terms of cost and time.

Additionally, options with a longer lead time run the risk of losing potential market while the construction is taking place. Once the capacity has been installed at a later stage in the timeline, the port has lesser moments to recover the investment. For instance, the option of installing an additional capacity of 1050 x1000TEU with a lead time of 8 years (after expansion total capacity of 1450 x1000TEU) and fixed end date. It is observed that, if the expansion is exercised in 2020 the expected NPV amounts to -26.73 Million EUR. While, if the option is exercised in 2023 the expected NPV amounts to -28.29 Million EUR. There is a savings of 1.5 Million EUR. There is a greater loss in value if the expansion is started in 2027 evidenced by the drop in ENPV to -32.131 Million EUR. When the resultant ENPV values of the 2027 option exercise are compared against a 2020 option exercise, there is an observed loss of 5.36 Million EUR.

However, in comparison to the option wherein the to be installed capacity is 525 x1000TEU with a lead time of 4 years (after expansion total capacity of 925 x1000TEU) and fixed end date. If the expansion is exercised in 2020 the expected NPV amounts to 8.38 Million EUR. While, after the exercising of multi-stage expansion option in 2020 and 2030 respectively, the expected NPV amounts to 7.744 Million EUR. The loss in ENPV between an option exercise in 2020 and 2020+2030 amounts to 0.64 Million EUR. This loss in ENPV is much lesser than what is observed in the case of large expansions with longer lead times.

4. **Flexibility has a value until a set time**
Expansions with the option of altering the scale are said to have an additional value (de Neufville and Schotles,2011) (Geltner and De Neufville,2018). However, in the recorded results, it is observed that only certain options have value in terms of flexibility. The value of flexibility is seen to diminish in options with longer lead times and excessive delay in the exercise of the expansion option. The current altering scale options are assumed to be exercised only in case of a certain expectation value of capacity exceedance. If the option exercise is delayed after these threshold moments, there is an observed reduction in net payoffs. Particularly, for flexible strategies, if there is a significant delay between multi-stage sequential expansions, there is a reduction in the new pay-offs. In the current case it is observed that after 2030, there is a spike in future throughput volumes. If the decision-maker protects flexible options with large magnitude expansions until 2035, it might prove to be financially inefficient.

   Flexible options are not required to cost less to the decision-maker. Rather it is more likely that the flexible option might have a greater cost premium due to potential delay and negative effects of economies of scale. For instance, a large expansion of FQFC (through optimising operations) performs economically better than that of flexible strategies of HQFQFC Flex (first investment is made in 2020 and then re-investment is done in 2027). In this example, flexibility has no value. This due to loss made on variable revenues which are earned by the port authority. However, flexibility allows reducing the exposure to disappointing net pay-offs. Waiting for the second moment of investment allows for acting based on the movements of the market. Therefore, there is a requirement for a trade-off based on the objectives of the decision-maker.

5. **Financial viability of the project also depends on the project timeline**
There is more to gain from the option when the project timeline is also longer. In case of longer timelines (>40 years), staging large capital expenditures will be helpful. This will allow for finding more information on the uncertainty parameters and allow for a better judgement on the investment.

   However longer timelines also run the risk of calculating erroneous option value. ROA does not account for competitive behaviour. The unaccounted uncertainty might make the calculated option values for longer timelines sensitive. In these instances, ROA in itself cannot provide a holistic analysis. A game theory-based approach ROA might be required. Balliauw et al.(2019b) presents a game theory-based ROA approach for two competing ports. Such an analysis will lead to greater information on the short-term and long-term plan adaptations.

6. **Expansion strategies is dependent on the port authority's risk appetite** The current application of ROA for the case study provides strategic foresight by allowing for Short -term planning through operations optimisation. And long-term planning by delaying or altering the scale of investment.

   This foresight provides the decision-maker with the option but not the obligation to exercise an expansion in the future. The outcomes matching the risk appetite and the objectives of the decision-maker can be said to produce the optimal pathway for the decision-maker. Moreover, in the context of the existing numerical model, the decision-maker has the choice to input modulate the outcomes of decision rules by changing capacity utilization rates or control exceedance value. A risk aversive decision-maker who wants to ensure that, the port is ready for future demand might have the option to use lower capacity utilization rates and lower control exceedance probabilities. Similar reasoning goes to the other extreme decision-makers, wherein they have the option to use higher utilization rates and higher control exceedance probabilities. Accounting for this feature provides the decision-maker to modulate the numerical RO model based on their needs. Although in the previous chapter a proposed optimal strategy for African Port is provided, the port authority can still modulate based on their risk appetite. This control feature adds to the novelty of the numerical model.

7. **Uncertainty increases as time progresses**
   The standard deviation within the results has been observed to reduce in the cases of flexible options. This implies the spread of NPV values for flexible options allows for tighter estimation of ENPV. Secondly, it is observed that the uncertainty in forecasts increases as the forecast period increases. This can be verified by observing the standard deviation of each year's Monte Carlo simulation. The use of the stochastic process along with the Monte Carlo simulations allows providing for 2500 data points for every year which allowed for analysing the standard deviation. The standard deviation in the simulation runs for 2045 was 2473.027% greater than that of the standard deviation for 2020. Therefore, with the increase in the forecast period, the standard deviation of the forecast volumes increases. This does not imply that ROA should be applied for shorter forecast periods. Such conclusions are difficult to be derived as ROA does not provide optimal boundaries for forecast periods.

7.3. Validation of Research

Limited validation of the research was conducted to understand whether the conceptual framework and the numerical model of ROA presents an added value for decision making for port infrastructures. More specifically, it was to understand the practitioner's perspective on the applicability and viability of the added value for ROA.

This was done by the reflection of two consultants from Royal HaskoningDHV on the results obtained from the current research.Table 7.1 mentions the details of the interviewees from the organisation.

Table 7.1: Details of the Interviewees

Code	Role	Group
C1	Senior Investment Advisor	Maritime & Aviation - Economics & Operations
C2	Consultant	Maritime & Aviation - Economics & Operations

The interviewees are also the two supervisors for this research from Royal HaskoningDHV. Both the interviewees are domain experts who have experience in financial modelling and advising clients on the decision making aspects of port infrastructures.

These interviewees were asked questions based on the devised conceptual framework, results of the case study and the implications of the results. These questions allowed for reflection of the results.

1. *Utility of ROA*
   Both the interviewees agreed that flexibility in terms of staging has value in the port planning process. They recognise that through ROA, a monetary value can be calculated for flexibility. Which they consider to be a useful metric. According to the C1 interviewee, this monetary value can be used to reason for staged market entry. Based on the results and implications of the case study, the C1 interviewee remarked that ROA allows generating additional operational insights into the expansion alternatives. However, through the introduction of this method, a completely new set of conclusions cannot be derived. C2 also agreed to these statements, And added, through valuing flexibility, a comparative analysis on the options can be used in the decision making. However, this value of flexibility cannot be used to influence the financial viability of an expansion plan.

   During the feasibility stages, together with the clients, the consultants assess the business case. More information on the assumptions is obtained by the clients as the stages progress. This according to the interviewees allows them, to obtain greater confidence estimates on the calculated values. As the decision-making process moves in an iterative stage, the validity of the assumptions are validated and the uncertainty on the final calculated value is reduced. This makes the interviewees unsure whether "ROA moves the needle"?

2. *Broader implications of ROA within the decision-making process*

   Both the interviewees agreed that the value of ROA lies in the shift from a linear and static perspective to a rather more probabilistic and estimate based perspective. According to C2, a numerical model based on ROA will allow for a shift to a detailed probabilistic approach.

   Interviewee C1 mentioned ROA can allow for identifying growth pathways which can prove essential to understanding the trade-offs between the options. These growth pathways can allow for the adaptation of the decision strategy for the expected growth.

3. *Transition from DCF to ROA*

   In terms of a qualitative solution, the interviewees place their agreement to use ROA for decision making. However, the interviewees suggest that the current sophistication of the model does not give them the confidence to use the model in the real-time client-facing case. According to the interviewees, the assumptions for the existing model requires to be validated by the technical experts within the organisation. Especially, the C2 interviewee mentioned that greater involvement of technical colleagues in the modelling process can allow for a transition to ROA. As a capacity-based approach was adopted in the current research, it is recognised that the validation of the technical feasibility is a limiting factor for practical implementation of the numerical ROA model.

4. *Adapting and integrating ROA to the workflow*

   The interviewees recognise that ROA allows for additional operational insights on the alternatives. However, for making the existing numerical model for adding value to the existing advice, interviewee C1 mentioned, “Take-Two steps back, simplify the model”. The number of scenarios for the case study creates computational complexity which might not be easy to explain. The interviewee further mentioned that “Take people by hand” so that they understand the process mechanics and the operational insights. To do this both the interviewees mentioned that, a fewer number of scenarios and a decision tree analysis will allow for paving the path to incorporate ROA in their practice. Both the interviewees remarked the difficulty in explaining the mechanics and results of a DCF analysis to the clients.

   Hence, introducing the current ROA will be difficult for the clients to grasp. Interviewee C2 further mentioned that there is a requirement to build a convincing narrative around the numerical model. This will allow in communicating the nuances of the results. Through effective data visualisations of the results, the C2 interviewee agrees that ROA can obtain more acceptance in practice.

   However, a precursor step is to involve the technical colleagues in the financial modelling exercise to make ROA truly convincing for the client. C1 interviewee also added that the finance team should also be included in the design stages to operationalise options thinking. Such involvement and collaboration can be used to calibrate the numerical model of ROA based on the use case.

5. *Limiting Factors*

   Both the interviewees mentioned the requirement of historical data was said to be one of the limiting factors of the model. A proper set of historical data can be expected in Western European countries. In the case of other ports, this might be a hit or miss case. The use of project indicators such as NPV and IRR are the project indicators that are used in the feasibility stages. However, in the latter stages of the decision making, other financing based key performance indicator is used. For instance, the focus is then maintained on whether the loan can be paid by the client and parameters such as Debt Service Coverage Ratio are utilized. ROA does not inform on those metrics which can prove to be a limiting factor.

   C2 interviewee especially mentioned the complexity of the methodology does not necessarily result in the limited usage of the model. According to the interviewee, the numerical model needs to work intuitively for the use case. The current conceptual framework allows for a step by step intuitive thinking. Based on the use case, the numerical model can be calibrated for the required analysis.

   C2 interviewee also interestingly does not see the computational complexity as a limiting factor. According to the interviewee, intuitiveness should not be confused with ease of modelling. If the model has a convincing narrative and allows for intuitive calculations, the complexity is a good trade-off.

   Options used in the current research are not validated for their technical and engineering feasibility. Such sequential installation of capacity with a set of gap years might not be possible. If the options are then checked for their technical feasibility the number of levels to the stage may be reduced.

The current model amounts to 420 MB which takes between 900 - 1200 seconds for computation. Both the interviewees mentioned that the analysis is required to be fast, flexible and easy to analyse. Interviewee C2 suggested a shift to Python might allow for faster computations.

6. *Use Cases for ROA*

   Real options analysis does provide a better insight into the structure of decision making more than as a full-fledged valuation tool. As mentioned earlier, with the progress in the stages of decision making, there is a shift in the indicators used in the evaluation of development or expansion plan. In those cases, a numerical model of ROA cannot be used as a valuation tool. Rather it can play the role of decision support. The decision support can allow for understanding the growth pathways and present the trade-offs between flexible and inflexible strategies.

   As far as using it for real-time cases. The use of ROA depends immensely upon the maturity of the client. If the client is well versed with decision analysis and requires a probabilistic and estimate based model. ROA can fit those use cases. These use cases will allow the consultants to ensure that the clients can comprehend the analysis and understand the additional insights which can be derived from the analysis. In these cases, ROA can be used to calculate the expected NPV. The interviewees were asked for their opinion on the use of this model in greenfield cases. According to the C2 interviewee, in the case of greenfield projects, the question is to understand the amount of market share that can be obtained from the project. The focus is not only on the forecasts but other macroeconomic indicators. Based on the sophistication of the existing numerical model, the interviewee was doubtful of the utility of the ROA in such cases.

Based on the above insights, the added value of ROA from the perspective of the experts can be extracted. ROA can be understood to be a decision support tool rather than a valuation tool. Through ROA growth pathways for development and expansion can be understood. Valuing the options for expansions can determine which options can be protected by the decision-maker. Valuing of the options also allows for calculating the value of flexibility, which is seen to be a significant purpose. This value of flexibility allows for substantiating the strategies of staging. Through ROA, the consultants can also understand the effect of the sequential installation of expansion modules. Additionally, the insights on delaying the expansion modules can also allow the decision-maker to receive more information on the market. Such insights can allow for replicating active management within the model.

7.4. Implication on Scientific and Practical relevance

The research intended to bridge the gaps of methods, evaluation and knowledge.

Addressing the Methodological Gap

Many articles in academia, use ROA based on standard implementation approaches of lattice method and Monte-Carlo simulations. Many of these applications conclude with the comparison of an inflexible strategy and a flexible strategy. Specifically for port infrastructural applications, these standard implementation approaches have been moulded by three significant articles of Taneja et al.(2011), Lagoudis et al.(2014) and Balliauw(2020). However, these approaches were limited in terms of practical relevance, transparency of assumptions and modelling concepts. Approaches by Balliauw(2020) and Balliauw et al.(Balliauw et al.) are far too theoretical in order to directly apply in practice. Although Lagoudis et al.(2014), provides an implementation approach focused on real-time cases, it lacks a clear explanation of assumptions and reasoning behind those assumptions. Finally, approach by Taneja et al.(2011) focus on a different subset of ROA which was not valid for this research. Hence, these approaches cannot be replicated due to their limiting factor. The devised conceptual framework involves practitioner's tools of Spreadsheet approaches, Monte-Carlo Simulations and probability estimations. A balance was struck between simplification and computational complexity. A numerical solution was designed through the conceptual which allows bypassing the theoretical equations but at the same time considers complex probability calculations. Through this research, a comprehensive framework was developed which accounts for the practical complexity of the decision making process. Additionally, the devised framework accounts for the theoretical approaches but verifies the assumptions based on its relevance for a practical case of port expansion.

Addressing the Knowledge Gap

To implement a numerical model of ROA for a case, there is firstly a requirement of a business case and a financial model. The financial model allows for understanding the forecasts, cash flow calculations and project indicators which will be then used for the ROA. Therefore, ROA builds on the static DCF model. Secondly, there is a requirement for historical throughput volumes at ports. ROA approaches are developed based on a stochastic process. These stochastic processes require the volatility parameter of throughput volumes. This can only be calculated using the historical throughput volumes. Hence, to apply for real-time cases, ROA can be suitably used in brownfield cases. The existing theoretical approaches do not define a clear approach for greenfield projects.

For port infrastructural applications, modelling using the assumptions of risk-neutrality and no-arbitrage based argument makes it complex. Rather an engineering-based approach based on de Neufville and Scholtes(de Neufville and Scholtes) and de Neufville et al.(2005) are observed to fit well in the context of Monte-Carlo simulations methodology. In cases where risk neutrality and no-arbitrage assumptions are not considered, real probabilities are required to be calculated. In the numerical model too, for capacity exceedance real probabilities are calculated. Therefore, during implementation, the decision-maker cannot use risk-neutral or objective probabilities of success.

From the perspective of influence on the business case, the results of this research indicate that the decision-maker can adapt their expansion strategies. This is done by calculating optimal moments and the magnitude of expansion based on decision rules. Additionally, based on the potential optimal moments of expansion, a boundary for the exercise moments for each option is achieved. With these results questions such as *Expansions for future demand? How much capacity will be required? Until when the decision can be postponed? When to expand? What should be the magnitude of expansion? What is the position of such an investment?* are answered. These results can be a particular use for the decision-maker, as it allows for developing adaptable strategies. These adaptable strategies will models the active management style of the decision-maker. This also allows the decision-maker to understand that staging and delaying an expansion has a monetary value. Moreover, these adaptable strategies present an alternative to the classical approach for capacity planning: planning for excess capacity. the current research approaches capacity planning as planning for potential demand and adapting based on real-time value. A similar capacity planning based approach for ports has been observed in Reyes et al.(2019. The results of this implementation suggest that changing the time moments and magnitudes expansion has a telling impact on the total project value and the net pay-offs.

Addressing the Evaluation Gap

Through this research, the value of flexibility is quantified for flexible expansion strategies for the African Port. However, it would be unfair to remark that, staging expansions is a new concept in the maritime industry that can only be valued using ROA methodologies. Indeed, staging can be valued using a static DCF model however it does not consider the underlying behaviour of the uncertainties and present alternative strategies. ROA allows for enhancing the static DCF model by filling the gaps of DCF model. A static DCF model will not respond in an optimal way for calculating timing and magnitudes of option. ROA allows for filling this gap, by assessing numerous possibilities of demand, options and testing for its sensitivity.

The current research allows for calculating the monetary value of flexibility. However, not in all cases, flexibility has a value, there are costs associated with it. Within the results to it is seen that it is only one of the options which perform better than the other flexible options when compared to their baseline inflexible options. So flexibility is a by-product of the real options And the sole aim is not just value flexibility. These results match with the work of Martani et al..

The ROA model alone cannot predict optimal magnitudes and timing moments of the investment. Ports as infrastructure are of strategic infrastructure and are said to be driven by strategic, geopolitical and political agendas. ROA numerical model cannot account for these agency problems. The numerical model assumes that the decision-maker is rational. Additionally, there are many stakeholders involved in the project and not all of them can be expected to make decisions in a rational and maximising attitude. Not accounting for these shortcomings trickles the notion of passive management in a real options model too.

Additionally, static DCF as stand-alone methodology cannot value flexibility. The additional scenario analysis on the single point estimates is based on the assumption that it will be the only path of uncertainty development and will most likely occur. ROA considers all the potential paths for the uncertainty state parameter.

The implementation of ROA was done using spreadsheets, decision rules and Monte Carlo analysis. This has been observed to be laborious. The current numerical model built on Microsoft excel was about 420 MB in size. Additionally, for each strategy, the model requires to run again which takes about approx. 900-1200 seconds. Therefore, the ease of implementing a ROA through a set of decision rules and Monte-Carlo simulations is computationally intensive and does not carry the ease of NPV. This finding is converse to the findings documented in de Neufville et al..

From the perspective of the experts, the value of ROA lies in its consideration of growth pathways and calculation of the value of flexibility. It was mentioned that ROA can allow for identifying growth pathways which can prove essential to understanding the trade-offs between the options. These growth pathways can allow for the adaptation of the decision strategy for the potential growth. Additionally, ROA allows for a shift from a linear and static perspective to a rather more probabilistic and estimate based perspective. To add value to the practice, the experts mention that there is a requirement of simplicity and fast computation which has not been achieved from the existing ROA model. ROA was also said to have an added value in the pre-feasibility and feasibility stages wherein the project assumptions and decisions are not sealed. In the latter stages of the project, the project is evaluated with the KPIs of Debt Service Coverage Ratio and loan repayment metrics which is not the outputs from ROA. This shift in indicators also suggests that the value of ROA for port decisions lies in decision support rather than valuation.

7.5. On aspects of generalization and usability

In the exploratory interview session when the interviewees were briefed on ROA, these were the questions which came across: *"What is the level of sophistication required? Where to get the data from? How can the quality of data be assured or validated? What is the quantity (years) of data required?"*. It was given an impression that ROA is a black box. However, it is based on the verification of the assumptions of the methodologies which will help in answering these questions. In the case of sophistication of the model, it can be said to vary based on the type and case of implementation. The value of ROA can be interesting for the organisation when it is investigated for flexibility "in" infrastructure. This implies that the design engineers create options for adaptability while designing for the infrastructure. these adaptation options can then be valued as flexible alternatives. Ideally, this level of sophistication will add value to the works of the organization. However, the first step towards this sophistication would be framing cases in terms of options thinking approach and valuing flexibility "on" infrastructure. It was understood from the exploratory interviews that, the availability of historical data is client dependent. In case of no historical data, it will be of less value to apply ROA. The estimation of future possibilities relies on the assumptions of this historical data. Therefore using benchmark values might result in misleading values. In the case of how many years worth of data is a matter which is less focused in ROA. However, enough data points must be available to result in a significant value occurring from the stationary test. This could be one of the ways to ascertain the quantity of data. The quality of the data can be verified based on the correlated macroeconomic indicators. it is said GDP is closely related to the behaviour of throughput volumes de Langen et al.(2018).

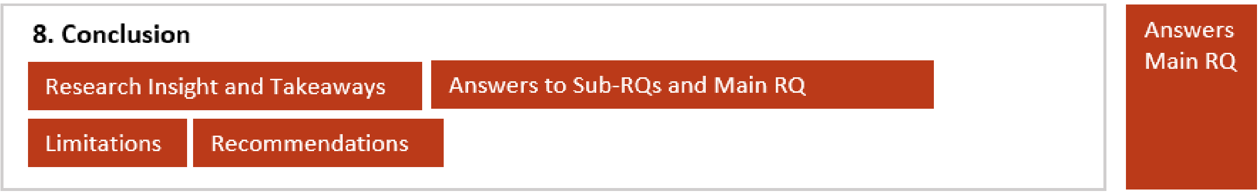
From the validation interviews, to increase the usability of a numerical model of ROA, it is first required to perfect decision tree analysis. This will allow for paving the path for options thinking. Secondly, to make the model more usable it is required that the models are intuitive and are built around a narrative. Finally, the models are required to be validated for their technical feasibility. Once the options are technically feasible, there is a possibility to integrate them into the existing workflow.

The generalization of the proposed conceptual framework and the numerical model can be said to be limited due to the focus maintained on brownfield expansion cases. Therefore, the devised items cannot be applied to a greenfield project. Additionally, there is a requirement of historical data on the chosen uncertainty state parameter, which can be said to limiting for projects where there is a paucity of historical data. It is the information on the uncertainty state parameter which is vital. Therefore, in cases wherein such data is not available, ROA holds little value. If the focus is maintained on any transportation network, the devised framework and the numerical model can be applied to model intervention strategies for expansion. Verification of the stochastic process would be the only criteria in such cases of implementations. However, it should not be expected that ROA will lead to a higher expected NPV value than the inflexible methodologies. Finally, ROA should be applied to the cases wherein the project is in its feasibility or pre-feasibility stages. This will allow for building the valuation model from an option thinking perspective.

8 Conclusion

Real households, Real businesses and Real governments do not optimize; they cope..
— John Kay and Mervyn King,

The conclusions derived from each of the sub research questions are presented in this final chapter. Through the results, analysis, discussion and validation of research, the main research question for this research has been addressed. Based on the process, the results and the analysis of the research, a set of Limitations and Recommendations are listed.



The success of a port is related to complex ties of inter-related factors. It involves a shift in trade lines, vessel sizes, current capacity, the economic atmosphere of the country, geographical location of the port. It is not just about the capacity of the port. Optimising for the optimal time and magnitude of expansion may not necessarily lead to maximised pay-offs. Unless the effect of other transport nodes is not considered on the port, it can be reasoned that, the true moments of expansion may not result in the anticipated adaptation strategy.

Although ROA as a method of valuation considers uncertainty, it is not a holistic method to value all the possible multiple sources of uncertainty. “It is in comfort that, one gets perturbed by the first face of adversity”. More than the use of sophisticated and intricate models, there is a requirement for a shift in attitude and mentality. The following paragraphs present the conclusion and final takeaways from this research.

8.1. Answers to the research question

***Sub RQ-1**: What can be learnt from the approaches of Real options Analysis and its applicability on infrastructural decision making?*

ROA as a methodology for decision making has been significantly implemented in infrastructural systems to value flexibility. It is the broad category of transportation infrastructure wherein many implementations are present. For infrastructural applications, two approaches are frequently used. Firstly, it is the lattice approach that is solved through backward induction or dynamic programming methods. The lattice approach considers the parameter of uncertainty to move upwards and downwards to create a recombining lattice. Monte-Carlo Simulations vary from the lattice approach as it is a forward-looking methodology that is applied in conjunction with a stochastic process to identify future possibilities. The combination of the stochastic process and the

Monte-Carlo simulations allows for providing several random paths for the uncertainty parameter. Frequently used uncertainty parameter involve demand uncertainty. Price related uncertainty(such as construction, material and equipment costs) have not been used frequently as a primary source of uncertainty. The objective of ROA application within the infrastructural application can be narrowed down to two priorities. Firstly, it is to calculate the value of flexibility modelled through staged strategies or options to alter the scale. Secondly, it is to maximise pay-offs which are modelled using options of altering scale These priorities allow for engineering flexibility in the decision making, which makes ROA attractive for infrastructural applications. Implementation through approaches such as MAD by Copeland and Antikarov(2001) and options pricing by Black and Scholes(1973) are numbered. This is due to the assumptions involved in Black and Scholes(1973) which relates to constant volatility rates and pricing of a European option. While Copeland and Antikarov(2001) has limited applications due to its simplistic applications which are not well validated. The use of Monte-Carlo simulations as a methodology for ROA for infrastructures is also tagged as an engineering approach. Such an approach focuses on engineering flexibility in the decision model. Complex theoretical assumptions of risk-neutrality and no-arbitrage are not considered in such an approach. It is the simplicity and its grounded theoretical framework that an engineering approach is more common in ROA implementations for infrastructural applications.

***Sub RQ-2** : What are the currently used process mechanics for modeling through Real Options Analysis specifically for port infrastructural decision making?*

Similar to ROA implementations for infrastructural decision making, port applications suggest that Monte-Carlo Simulations and Lattice approach are the most frequently used approaches. Taneja et al.(2011) presents values real options by valuing flexibility "in" infrastructure. Such an approach focuses on adaptive port planning which is then used by Reyes et al.(2019). Both of these application involves a Monte-Carlo simulation approach involving risk-adjusted discount rates. These two implementations involve data from a real case study, thereby reflecting the complexity of modelling through ROA in port context. Lagoudis et al.(2014), presents a radically different approach wherein the first half approach focuses on identifying the bottlenecks in the current port. The second half of the approach focuses on valuing the intervention strategy through de Neufville and Schotles(2011) engineering approach. Monte-Carlo simulations are used as a method for ROA wherein the cash flows are adjusted using risk-adjusted rates. Finally, the third significant approach by Balliauw(2020) models ROA for a simulated case with a GBM and dynamic programming approach. Balliauw(2020) focuses on the effects of time to build might have on the option value. In port implementations, demand is the primary source of uncertainty. Which are modelled using the stochastic process of GBM. It is the use of risk-adjusted discount rates along with an engineering approach that is more popular within articles for ROA for port infrastructural decision making.

***Sub RQ-3**: What is the practitioner's perspective on the parameters of uncertainty and financial valuation of port infrastructural decision making?*

The perspective of the interviewee varied based on their backgrounds. For a design engineer, it was the capacity and structure. On the other hand, for a financial consultant, it was the financial feasibility and the business case. The interviewees are involved in many stages of the decision-making process. However, it is during the pre-feasibility and feasibility stages where they are involved frequently. From the exploratory interviews, it was the uncertainty in demand which was mentioned to be a significant factor of uncertainty that has a monumental influence on the financial model. Following this, it is price related (construction, equipment and material costs) uncertainties and institutional uncertainty which influence the viability and the complexity of the decision-making process. Interviewees mentioned instances wherein, the client does not have clear specifications of development or expansion plan. This results in a certain level of ambiguity trickle down to the financial model results.

According to seven out of the eight interviewees, the current advice on port expansion follows a staged market entry approach. Although this is not valued similar to ROA, the current consultants consider smaller expansion scenarios. However, this is not the case in all instances. Some port authorities are said to have their own biases and consider the financial analyses as a way of understanding their position on the investment. In other cases, during the ideation and feasibility stages, the client is looking forward to a high-level analysis which indicates the worthiness of pursuing a certain development or expansion plan. The consideration of uncertainty is done through Monte-Carlo simulations, scenario analysis and sensitivity analysis. However, the level to which the analysis is conducted varies based on the time and budget allocated by the client. Except for this limiting factor, it was also mentioned that the level of uncertainty consideration depends upon the data provided by the client and the communicability of the analysis. Their view of the interviewees on uncertainty was also highly dependent on the phases they are involved in. In the feasibility stages of the project, the uncertainty around the input parameters was said to be greater than during the detailed design phase of this project. Due to acquiring more information and validation of the baseline assumption, this uncertainty is reduced. Through the interviews, most of them mentioned that the analyses are required to be appropriately conveyed to the client which can then result in actionable strategies. The requirement of data for such analysis also depends upon the maturity of the client and the stage of consultation.

Sub RQ-4*: How does the published implementation approaches and the requirements lead to a real options application for port infrastructures?*

The currently published implementation approaches vary significantly. The nature of the current research involved a focus on flexibility “on” systems. Thereby, making the approaches of Lagoudis et al.(2014) and Balliauw(2020) significantly valid for the current research context. Due to the practical relevance of Lagoudis et al.(2014), the conceptual framework involved many elements from this approach (e.g. the engineering approach). However, to analyse the options for optimal time and magnitude, the approach from Balliauw(2020) was used. The devised framework is put together by elements from a variety of past approaches. The conceptual framework is devised using five key steps. The framework accounts for practical relevance, comprehensibility and transparency. Through accounting for practical relevance and comprehensibility, the conceptual framework can be implemented on Microsoft Excel with known practitioner-oriented tools such as Monte-Carlo simulations, probabilistic and sensitivity analysis. The transparency of the conceptual framework indicates that the assumptions mentioned in the conceptual framework are founded in literature for its subsequent implementation.

Firstly, to implement the proposed conceptual framework and numerical ROA model, there is a requirement for a baseline DCF model which includes relevant cash-flows (DEVEX, CAPEX, OPEX and revenues) and project indicators (NPV). Additional, there is a requirement for historical throughput (in case of demand uncertainty) and tariffs (in case of price uncertainty). An underlying project business case highlighting the objective of the port authority will be needed for substantially operationalising the numerical ROA model. The second step involves estimating future possibilities using the combination of a stochastic process along with Monte-Carlo Simulations. Thirdly,the identification of the options can be done using the questionnaire presented by Taneja et al.(2010) and screening model presented by de Neufville and Schotles(2011). Additionally, using decision rules potential optimal time moments of expansion are filtered which is similar to Cardin et al.(2017a). Fourthly, based on these time moments the cash-flows are calculated as a distribution for each of the identified option and discounted using WACC. Finally, the options analysis for optimal moment and expansion is conducted using expectation values and finding moment wherein pay-offs are maximised. Through this analysis value of flexibility is calculated using the approach of Cardin et al.(2007).

Therefore, the proposed conceptual framework and the numerical model allow for a contextualised ROA implementation for port infrastructures. Through the utilization of the proposed model, the expansion decisions can be modelled for the decision-maker. Specifically, the options of altering scale and postponement can be explored using the proposed model. Through the implementation of the proposed framework and the numerical model, the decision-maker can obtain operational insights on the questions of: *Expansions for future demand? How much capacity will be required? Until when the decision can be postponed? When to expand? What should be the magnitude of expansion? What is the position of such an investment? What will be the monetary savings through staging?*

- ***Sub RQ-5****: What can be derived from the comparison of the traditional valuation with the suggested model of real options within the context of the current case of port expansion?*

The value of flexibility is monetised through the valuation of staged strategies. An inflexible strategy involves zero value of flexibility. This is due to all the magnitude of expansion is installed at once. While, a flexible strategy involves stages expansions wherein the total capacity is installed in discrete stages.

A static DCF lack the capacity for valuing flexible strategies based on multiple paths of the future. This is due to the static and linear calculations involved within DCF models do not respond in an optimal way for calculating probabilistic outcomes for various timing and magnitudes of expansion. The output parameters yielded by the implementation of the proposed ROA based framework and numerical model for the African Port are compared against the output of a static DCF model in Table 8.1.

Table 8.1: Comparison between static DCF and numerical model of ROA for the case Study

Parameter	DCF	ROA model [Flexible Strategies]	Remarks
Number of flexible levels available for expansions	0	4	The current DCF model only considers inflexible strategies. The current ROA model allows for multi-stage sequential expansions with four expansion modules.
Comparison of Expected NPV (in Million EUR)			
Expected NPV when the total expansion magnitude is 525,000 TEU	8.336	9.112	0.776 Million EUR will be saved by the port authority if the port authority models the expansion strategy based on flexibility.
Expected NPV when the total expansion magnitude is 750,000 TEU	-13.3115	-11.44334	1.86816 Million EUR will be saved by the port authority if the port authority models the expansion strategy based on flexibility.
Expected NPV when the total expansion magnitude is 1050,000 TEU	-26.17541	-29.74093	Flexible multi-stage sequential expansions do not have a value in this case. For this case, it is better to execute a single-stage complete expansion by the said capacity.
Comparison of value of flexibility (in Million EUR)			
When the total expansion magnitude is 525,000 TEU	0	0.776	The monetary benefit which can be gained through adding flexibility amounts to 0.776 Million EUR.
When the total expansion magnitude is 750,000 TEU	0	1.86816	The monetary benefit which can be gained through adding flexibility amounts to 1.86816 Million EUR.
When the total expansion magnitude is 1050,000 TEU	0	0	There is no monetary benefit by using flexible strategies.
Comparison of start time of construction			
When the total expansion magnitude is 525,000 TEU	2020	2020 and 2029	ROA allows for breaking the construction of the expansion plan in stages. For this case, the port authority can choose to wait and see until the end of 2026 and 2028. Hence, does not fall into the trap of considering a set expansion date for the complete expansion.
When the total expansion magnitude is 750,000 TEU	2020	2020 and 2027	
When the total expansion magnitude is 1050,000 TEU	2020	2020 and 2027	

The implementation of ROA allows for calculating a monetary value for flexibility. And present the monetary savings which can be achieved through postponing the decisions. However, through ROA, not all staged expansion consists of a monetary value of flexibility. From a total of 6 flexible strategies, it is only 3 strategies wherein there is a value of flexibility. Therefore, the application of ROA need not always result in a value of flexibility greater than that of 0. Secondly, static options which can be only optimised for operations present an additional utility. The static options which are optimised for operations show greater expected NPV values than that of all the flexible strategies (except for HQHQHC). For instance, for an expansion case of 750,000 TEU, the comparison of option by higher operational utilization against current levels of operational utilization allows for saving 4.12 Million EUR.

This implies that more than staging it is the optimisation of operations that present a utility in this case. Another argument for a static option with optimisation of operations, allows the port authority to wait and observe, the changes in markets, technology or environmental regulations.

The optimal strategy of adaptation calculated through the numerical ROA model for the case is shown by the expansion option wherein the total magnitude of expansion is 525,000 TEU (first moment of expansion = 2020 | second moment of expansion = 2027 | first-moment magnitude of expansion = 225,000 TEU | second-moment magnitude of expansion = 300,000 TEU). The reason for this option being the optimal expansion adaptation stems from its highest expected NPV value in comparison to other values. Additionally, this option has a value of flexibility greater than 0. The expected NPV for the proposed adapted strategy amount to 9.112 Million EUR. The comparison of this expected NPV value against the expected NPV for a static DCF shows that the port authority can save 17.063 Million EUR by adopting the proposed expansion strategy. Therefore, the current expansion plan adopted by the Port Authority of the african port of installing 1050,000 TEU does not pose a benefit in terms of the project outcome.

The ROA and the static DCF approach for the current case study performs similarly when it comes to the consideration of agency problems and the dynamics of competition. ROA is an enhanced form of static DCF which uses the assumptions present in the static DCF model. Therefore, in case of erroneous assumptions, ROA analysis cannot magically result in a valuable detailed analysis. ROA is not an antidote to all the shortcomings of a static DCF approach. Therefore, for the port authority, it will be valuable if they do not let either of the models think and analysing part for them. Ultimately, decisions are made by humans, so the decision-maker needs to externalise themselves to the model and ask what the model should do? what can be done with the results? Answers on these matters will help the decision-maker to structure their decisions better regardless of the nature of the model. Valid answers will empower the ROA numerical model.

Main RQ: ***What is the potential value of implementing Real Options Analysis within port infrastructural decision making?***

Firstly, ROA should not be mistaken for a forecasting methodology. Rather ROA allows for calculating and analysing multiple pathways through which an expansion plan can be adapted. Through, ROA, the flexible strategies provides a monetary value on flexibility. And indirectly benefits the decision-maker to wait and watch for the developments in the market. This adaptation of the plan will help the port authorities to reduce their exposure to longer payback periods. According to the experts in the validation interviews, the added benefit of ROA is associated with its ability to consider multi[le growth pathways. Moreover, valuing flexibility will allow them for substantiating claims around staging strategy. Therefore, the first added value of ROA is its ability to consider numerous possibilities and the calculation of the value of flexibility.

Secondly, ROA allows for the consideration of managerial flexibility and active management. It can allow developing strategic foresight from the point of view of the decision-maker. Implementation of a case study has shown that ROA allows for developing strategic foresight in terms of both short-term and long-term goals. Unlike static DCF approaches ROA does not follow: "predict and control strategies" and planning for excess capacity. As the focus is maintained on flexibility the "Now or Never" notion of the inflexible strategies valued through static DCF can be bypassed. Hence, the second added value of ROA is to develop and analyse adaptation strategies that can be updated based on the new information. Thirdly, ROA implementation can be said to be useful in the pre-feasibility stages, wherein the possibilities for multiple timing and magnitudes can b checked. The sophistication of the assumptions can be scaled based on the data. But using ROA on a later stage will require a fundamental change to the way the financial model is built, which might make it time-consuming and occupationally intensive.

Fourthly, the added value of ROA is the transition to probabilistic models. Through the use of stochastic processes and Monte-Carlo simulations, cash flows can be calculated as distributions. This can allow for understanding the probability of occurrence for a certainty value of NPV. This an added benefit on static DCF model as there is no supplementary analysis required to the ROA numerical model. To put it simply, the combination of scenario analysis, Monte-Carlo simulations and probabilistic analysis under one umbrella of ROA makes calculations more efficient and allows for building a narrative around the model.

However, RO can prove to be of little value in cases wherein there is no historical data available on the underlying uncertainty variable. This too was mentioned by the experts in the validation interviews. In cases wherein such data is available, it must be checked for its quality and assumptions. ROA like other models of data analytics follow the notion of: "Garbage in, Garbage out". ROA can be used for opportunistic use. Unlike the financial options, wherein the only objective is to maximise profits, there can be other opportunistic agendas in the case of decision-makers involved with real assets. The assumptions can be changed to serve this opportunistic behaviour. This could further lead to agency problems. The value of ROA based on current results is also limited due to its assumptions on the technical feasibility of the options. According to the experts, the benefit of ROA lies when both the technical and financial team collaborates and co-creates flexibility in both the design and the financial model. The essence of ROA diminishes as soon as the evaluation is done based on the polarity of Mean NPV value. At the crux of ROA is to use the resultant distribution of NPV to identify for likelihoods, probability of occurrence and expectation values. The extra time of these analyses might blur the communicability of the results to a decision-maker.

Through ROA the decision-maker can learn more about their position on the investment. ROA is a way of assessing alternative strategies which can be adapted based on the consideration of multiple scenarios (which are influenced by the uncertainty parameter) that are affected by shocks to result in a distribution of outcomes that can allow for probabilistic analysis. Through the application of ROA, there is a significant added benefit in terms of process mechanics and the final calculated outcomes. However, the benefit of ROA lies more in terms of decision support than valuation itself.

8.2. Limitations

ROA as a theory is observed to be sound. However, it is the implementations of ROA which limit the ability to derive actionable results. Prominently Borison(2003) and Triantis(2005), highlight the short-comings of ROA as a practice-oriented model. In this research too, limitations have been characterised into two aspects. The first is the limitations of the framework; while, the second is the limitations of results.

- Limitations of the framework:
    1. The limited applicability to brownfield port expansion projects. The conceptual framework proposes the use of GBM which as a random walk process requires historical data for the throughput volumes. This bars the use of a conceptual framework on greenfield projects. Additionally, it cannot be expected from all the port authorities to have the magnitude and quality of historical data. In case the port authority has data, the question of: "How many years of data?", has not been addressed in this research. It is plausible that the decision-maker might get an erroneous output due to inadequacies in the stochastic process and magnitude of data. These focus questions were considered to be out of scope for the current research as a deeper evaluation of ROA mechanics will be required.
    2. The current research does not focus on the validation of the technical feasibility of the options. It is assumed that the capacity can be installed in a multi-stage sequential manner. Therefore, this assumption might not present the true picture. Secondly, the current research does not consider the time required for decision making.
    3. The selection of stochastic process has not been discussed in depth. Within the numerical implementation, the Augmented Dickey-Fuller test was used to validate the use of GBM. However, there can be cases where this test might not suffice. The cases wherein the data are not enough to determine to indicate the presence of the stationery property. Else the cases wherein the number of data points might influence the outcome of the test.
    4. The stochastic process employed for estimating future possibilities does not account for the macro-economic factors of the country. It is plausible that these future possibilities might be superficial in comparison to deeper market analysis based on various trends and trend breakers.
    5. Monte Carlo simulations are proposed and implemented in this research as a method for estimating possibilities for the future. However, the number of iterations required for these simulations have not determined. The number of iterations can be claimed to have a significant influence on the final option value. Too few iterations might lead to values with very large variance. Too many iterations might lead to a long computational time.
    6. The conceptual framework does not consider the influence of events in the competitive landscape. Real-life decision making involves staying relevant and staying competitive as a port. ROA as a stand-alone methodology does not offer many insights into these points.
    7. Due to the computational intensity of the numerical model, the ease of debugging errors is also observed to reduce. This will be a particularly limiting factor when there are iterations required in the assumptions or the calculation procedures.
- Limitations of the results:
    1. The proposed and the implemented numerical model is computationally demanding. This computational intensity might result in lower acceptance from practitioners and clients for using such a time-consuming analysis. In the current research, the numerical model was devised on Microsoft Excel; while, the analysis was done on Python. This switching over of platforms adds more interface, thereby limiting the practical applicability of such a model in practice.
    2. The numerical model includes many assumptions to calculate the cash flows. The option values can be manipulated by the decision-maker based on the input assumptions. Similarly, the decision rules calculations can be opportunistically used by the decision-maker. Therefore, the numerical model does not account for agency problems.
    3. The focus was maintained on expansion strategies either by altering scale and postponing the investment. However, there are other options such as abandoning investments or growth-related options that were not evaluated for the case. These options were not embedded in the case study, making the results limited to the considered options.

4. The objective of the research was to design and evaluate an implementation case of ROA. Due to the additional requirement of an industry-specific background and complexity, flexibility “in” infrastructure was not evaluated. The implications of these results are limited to cases of flexibility “on” infrastructure.
5. The implementation was carried out for a single study due to the complexity of ROA and the associated constraints of computation. These results can be generalised to all brownfield projects consisting of similar uncertainties. However, it cannot be generalised to all kind of infrastructure as these results have not been compared and analysed to call the “implications of results” a trend.
6. The forecasting is done using a stochastic process that does not take into the macroeconomic indicators and the other factors which affect the behaviour of the variables. Real Options Analysis is not a forecasting procedure and uses stochastic processes to model the uncertainty. Therefore, the current forecasts lack the depth and assumptions as used within causal models for traffic forecasting or neural networks or regression models.
7. The decision rules are context-dependent and the confidence level of the exceedance probabilities is to the discretion of the decision-maker. The calculated moment(s) of capacity exceedance relies heavily on the confidence level. Therefore, changes in confidence level will result in many different moments (s) of investment which will add to the computational difficulty.

8.3. Recommendations

The current research focused on the research gaps of methods, evaluation and knowledge. Through the conceptual framework and the numerical model, the methodological gap has been addressed. With the use of a test case of African Port, the implementation of ROA is evaluated for its added-value (addressed the evaluation gap. Finally, through the analysis of results, the influence of ROA on a business case is recorded. This along with clarity on assumptions and process mechanics (developed through the conceptual framework) allowed for addressing the knowledge gap. While the discussion of these gaps, the shortcomings of ROA was observed. Following are the recommendations:

8.3.1. Recommendations for Future Research

1. ROA works have been focused on showing the added value which can be obtained through this analysis. However, there are limited domain-specific approaches wherein there is an in-depth discussion on the influence of the domain on the ROA approaches. Extending the existing approaches to different fields of implementation can be said to inhibit the growth of ROA as a practical methodology. Therefore, there is a requirement of industry-specific focus and adapting the existing methodologies for the field of implementation. Finally, based on these specific approaches, research on “best practices” to apply such a methodology will improve its practical relevance and acceptance.

2. There is a requirement for scaling research on the theoretical mechanics of ROA. The current attempts at addressing these issues in terms of a variety of discount rates, option mechanics and approaches. However, the assumptions relating to costs, utilization and technical feasibility are still open to interpretation and manipulation. Research on the theoretical mechanics will allow for further validation of the assumptions of ROA mechanics for infrastructural decision making.

3. Unlike demand uncertainty, price-related uncertainties have not been significantly used in ROA. Similar to this trend, this research too focuses on demand uncertainty due to its relevance in literature and findings from exploratory interviews. However, it was also understood from exploratory interviews that, CAPEX calculations are particularly subjected to uncertainties arising from construction, equipment and material costs. Therefore, consideration of price-related uncertainties will help sharpen ROA implementations for port infrastructural applications. Additionally, with the rise in digitisation and smart ports, there is a requirement of considering these uncertainties emerging from a technological standpoint.

4. Comparing the real outcomes of a static decision strategy against a RO model in an ex-post methodology will allow for an interesting comparison between the real and anticipated outcomes. Additionally, it will allow for a better understanding of the added value of the flexible strategies.

8.3.2. Recommendations for Practice

1. ROA as a methodology has value in practice only if the assumptions are verified and the mechanics are implemented correctly. Under tight budget and time constraints, ROA will prove expensive as a methodology. In such cases, it will be helpful if the problem is framed as a decision tree based on multiple scenarios. Although decision tree analysis does not capture[1] the essence of ROA, it still provides a foundation for an options thinking approach.

2. ROA implementations require time for development which can be done in iterative stages. As a part of recording leanings for each project, it will be helpful if the consultants can reflect on the project from a qualitative perspective of options thinking. To implement a full-fledged ROA model, the consultants need to grasp and frame every problem in terms of options methodology. Such reflections will help in grasping the essence of ROA. Finally, developing smaller use cases of historical projects will allow for iterative development of a generalised RO model for the organisation.

3. The consultants should focus on valuing flexible strategies for a range of scenarios. Optimal magnitude is observed to have a statistically telling effect. Expansion through static strategies might result in excess capacity which will reflect in the financial model as a lower NPV value. Therefore, the consultants should employ systems thinking while deriving these flexible as it will allow determining the points of magnitude where the expansion can be stopped.

4. The potential of ROA lies in strategies that focus on flexibility “in” systems. Considering the technical, design and planning expertise at the organisation, it will benefit, if these teams collaborate with financial modelling teams early on. For instance, Taneja et al.(2011, showed if larger load-bearing foundations for a warehouse are built, then the decision-maker has the option to expand the number of warehouse levels based on demand. Similarly, for port projects, the design team can provide inputs to the financial modelling team on such adaptations; which can then be valued using a ROA model. Through this proposition, more adaptable strategies can be employed.

5. Adoption of any new methodology requires acceptance from both the supply and the demand side. Therefore, the consultants along with their advice can present the client the advantages of flexible valuation approaches such as ROA. Steps to convince the clients to record historical data with accuracy will be beneficial for applying ROA in case of follow-up consultations.

6. Regardless of the implementation of ROA, efforts in validating the baseline assumptions will be helpful. The outcomes of the static DCF model are influenced through these assumptions. Capturing the variance in these assumptions through a data-driven approach will be beneficial to capture the uncertainty stemming from these assumptions.

[1] The essence of ROA is to consider numerous paths of future development. It allows for a shift from linear calculations to probabilistic based calculations. A decision tree analysis does not allow for such a dynamic modelling process. In contrast to ROA, decision trees employ objective probabilities which are not necessarily calculated from the probabilistic analysis.

9 APPENDIX-A

9.1. Exploratory Interview Protocol

This section includes the protocol and the questions which were asked to the experts during the exploratory interviews.

Date	
Name Interviewee	
Organization	
Designation	
Name Interviewer	Adithya Eswaran

Consent Form

I _________________________ agree to participate in this research study conducted by to Adithya Eswaran a Graduation intern at Royal HaskoningDHV. I place my agreement in treating the objective and the goals of the research shared to me as strictly confidential.

I realise that the interview will be audio-recorded and transcribed for the thesis. Further this I realise that I can withdraw at any time or refuse to answer any question without any consequences of any kind.

I have had the purpose and nature of the study explained to me in writing and I have had the opportunity to ask questions about the study. It is my understanding that all information I provide for this study will be treated confidentially.

I have been informed that a transcript of my interview will be held by the researcher until the course of his/her thesis. Until this period, I understand, I will be provided with a transcript of the interview and I am free to voice my concerns related to the data collected.

Finally, I have access to contact the researcher to seek further clarification and information about the use of my data.

____

Signature of the participant

____

Signature of the researcher

Date of Signature:

R:1- Research Objective

The research objective of the proposed thesis is "To explore the methodology for applying real options theory particularly concerning the additional value presented within the port investments by assessing the potential of real options within port investments through the comparison of the existing valuation model at Royal HaskoningDHV and the real options model created within this proposed thesis."

The primary objective to provide recommendations for the scientific community and the organization for applying real options theory presents itself with both theoretical and practice-oriented relevance. In order, to provide recommendations to the organization, it can be said that, a design approach must be undertaken The results and the analysis of this design approach will aid in making the research relevant to theory or academia. The same results and analysis will also aid in making the recommendation fro the organization.

R:2- Objective of the interviews

1) Understand the perspective of different individuals about the uncertainty variables which are dominant in the port industry.

2) Understand the perspective of different individuals about how uncertainty is tackled in the current financial models and market forecasts.

3) Understand the assumptions which are taken into account for port planning (financial and design).

4) Understand the planning protocol for port design and development.

5) Understand the protocol for financial modelling and market forecasts.

R:3- Introduction

1) Provide a brief presentation about real options and research set up.
2) Explain what is the necessity of RO in ports.

Section-1: Background

1) What is the line of your expertise?
2) What is your job function at RHDHV?
3) How long have you been part of the team at RHDHV?
4) Quantify the total number of years that you have been involved in this field of work.

Section-2: Introductory Questions

1) What are the stages of development are you mostly involved in (about port development)?
2) What is your specific role in port planning/port investments in the specific stage of involvement?

Ask the interviewee to reflect upon the following questions based on his/her experience:

3) How would you characterise port investments to be? (only for E&O)
4) How would you describe the characteristics of port planning?
5) What are the kinds of exogenous uncertainty factors are involved in port planning?
6) What are the kinds of endogenous uncertainty factors are involved in port planning?
7) What is the perception of the risks and uncertainty factors involved in port planning or port investments?
8) What is your familiarity with respective to adaptive port planning?
9) What is your familiarity with flexible port investment strategies? (only for E&O)

Section-3: Main Questions

1) What are the main drivers for the port design?
2) What is the purpose of the current financial model created by the team? (only E&O team)
3) What kind of information are vital for design in ports?
4) What kind of information (variables and parameters) are vital for financial modelling of port investments? (only for E&O)
5) How would you characterise the limited availability of background information on a port project?
    1. How does it affect the design?
    2. How does it affect the financial model?
    3. How does it affect the decision-making process?
6) With the current sophistication of financial models and designs is it possible to switch between different capacity volume handling to defer the investment at a later stage?
7) What according to you are the risks within port investments? (only E&O team)
8) Do the current financial models and design sophistication try to capture the upside of the risk?
9) According to you what are the variables which affect the technical life of a port?

- Classify based on known known, unknown known, known unknown, unknown unknown?

10) According to you what are the variables which affect the economic life of a port?
11) How does the current financial model help in making decisions for the investor/port authority (only E&O team)?
12) What are the measures taken to account for volatility in the current financial models?
13) What are the assumptions made for forecasting of demand?
14) What are the explicit assumptions made by the design team for port planning?
15) Can you describe the protocol taken for market risks?

16) What are the steps involved in the design process for ports?
    a. What induces complexity within this stage?
17) What are the steps involved in the forecasting process for ports?
    a. What induces complexity within this stage?
18) What are the steps involved in the financial modelling process for port investments?
    a. What induces complexity within this stage?

Section-4: Closure Questions

1) Do you have moments of reflection of your methods and take the lessons learned to the next project?
2) Is there been a very notable lesson learned through your experience so far?
3) Are there any learnings particular to the factors of :
    - Complexity
    - Tackling a lack of information
    - Identification of factors inducing uncertainty
    - Tackling factors causing uncertainty
4) Have you considered design options which can interact with each other?
5) Have you considered an option where the design team can look at the interaction of the design model with the financial model?
6) From your experience what limits your capability:
    a. To create stochastic financial models
    b. To create Flexible design option

Motivate the interviewee to come with an example which involves RO thinking.

9.2. Validation Interview Protocol

This section includes the protocol and the questions which were asked to the experts during the limited validation interviews.

The following questions were asked during the validation session with experts. These experts were a part of this research as supervisors.

Section-1: Specific to Conceptual Framework and Numerical Model

1. How would you assess the conceptual framework and the numerical model in terms of the following:
    a. Its difference from a static DCF model.
    b. Feasibility to use it in a numerical model for your further projects?
    c. Validity of the assumptions for port applications.
    d. Usability for creating decision support for port investments?
2. Do you think the effort of operationalising the conceptual framework allows for added analysis for the client?
3. What according to you are the favourable use cases for the conceptual framework of ROA?
4. Based on your experience in the financial modelling for port investments, what considerations are ignored in the current conceptual framework?
5. Through the use of a numerical model of ROA, do you think, flexible expansion strategies can be sufficiently modelled?
6. Would you consider, ROA allows for better consideration of flexible strategies?
7. Based on the results of the numerical, would you use ROA as a decision support tool or as a full-fledged valuation methodology?

Section-2: Broad questions on the implications of the results

1. What according to you are the limitations of such a numerical model in terms of:
    a. Communicability
    b. Data requirements
    c. Reporting
2. What according to you might be the limitations for its application in more real-life projects?
3. Based on the current display of ROA framework and its implication:
    - Do you think the analysis is comprehensive in terms of decision support?
    - Do you reckon that a consultant at your organisation can replicate this methodology for other cases based on the current level of sophistication?
    - Would you consider it as the foundation for transitioning to a ROA based decision model?
4. What would you suggest as improvements to the existing contextualised methodology to :
    a. Increase its utilisation in the organisation
    b. Improve its user-friendliness.
    c. Improve the derived insights
5. What are the major limiting factors of the proposed ROA model?

9.3. Case Data Exploration

9.3.1. Cash Flow Assumptions

This subsection presents the assumptions for calculating the cash flow assumptions for the expansion plan for African Port. Table 9.1 presents these assumptions for CAPEX, OPEX and revenues calculations. These assumptions are derived from the static DCF financial model for the case study.

Table 9.1: Model Assumptions used for Port Authority

Cash Flow Breakdown : Level 1	Cash Flow Breakdown : Level 2	Specifications	Unit	Value
CAPEX	Common Infrastructure		Million EUR	350
Revenues	Fixed Concession fees	Fixed Concession fee (2025 - 2034)	Million EUR	3.0
		Fixed Concession fee (2035 - 2049)	Million EUR	3.5
	Variable Concession fees	Variable Concession fee (2026 - 2035)	EUR / TEU	40.33
		Variable Concession fee (2036 - 2049)	EUR / TEU	45.0
	Port Dues	Port dues for feeder vessels	EUR / call	1259
		Port dues for medium vessels	EUR / call	3114
		Port dues for large vessels	EUR / call	5927
OPEX	Maintenance OPEX		%	1
	General OPEX		%	3

9.3.2. Forecast Volumes

9.3.3. Constrained TEU Volumes

Constrained TEU volumes

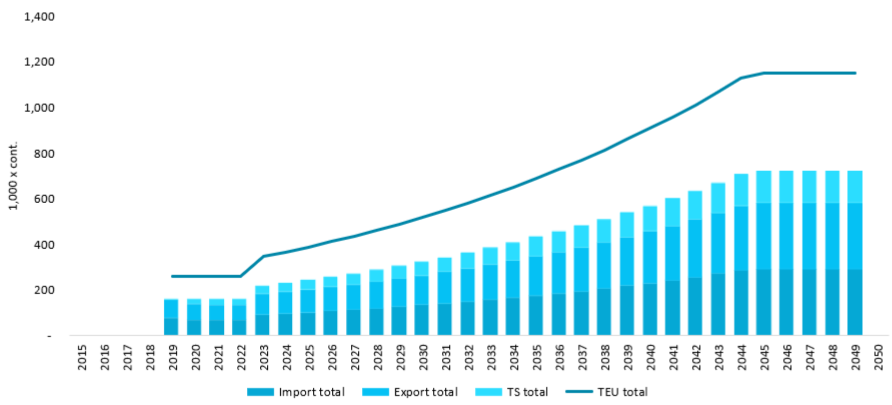


Figure 9.1: Total Constrained Forecasted Volumes for pessimistic scenario against time

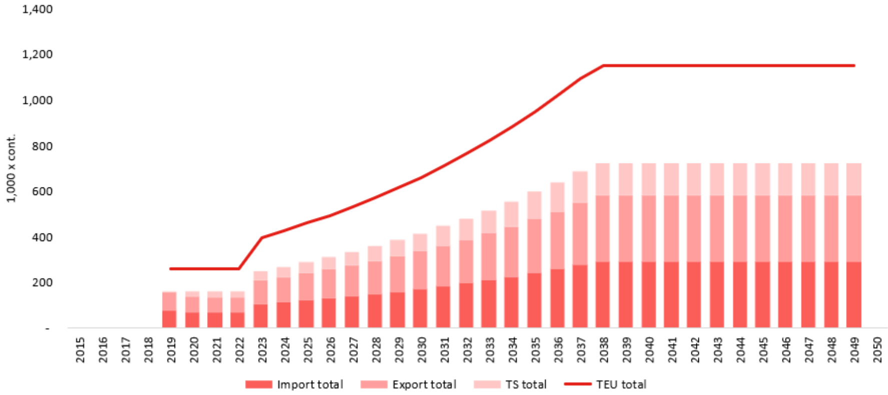


Figure 9.2: Total Constrained Forecasted Volumes for middle scenario against time

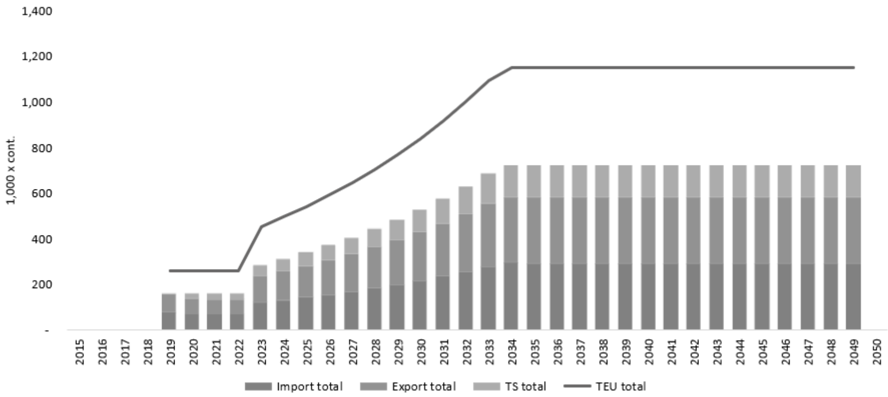


Figure 9.3: Total Constrained Forecasted Volumes for optimistic scenario against time

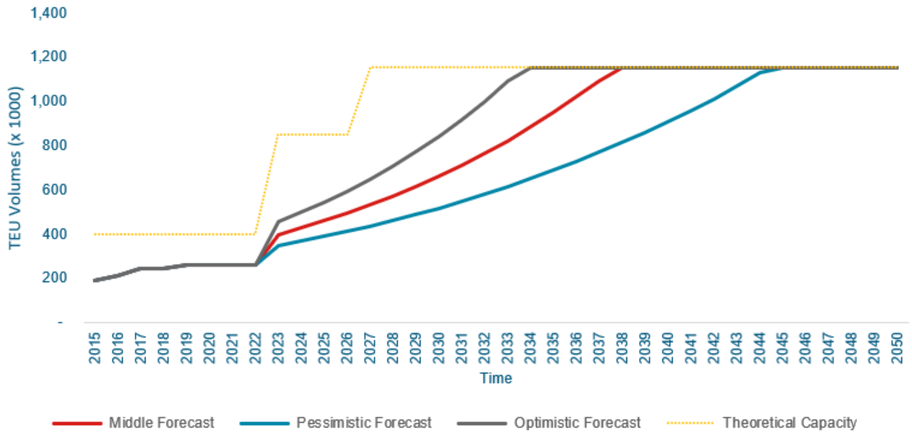


Figure 9.4: Constrained Forecasts based on scenarios
The plot puts the forecasted volumes in perspective against the operational capacity of the port (hence, constrained forecast).

9.3.4. Model Results - Cash Flows

This subsection presents the results of the cash flow calculations involved in the current static DCF model for the African Port.

Cash flows :

The relevant cash flows for the port authority (as visualised Figure 4.5) in involve revenues, CAPEX, DEVEX and OPEX. These cash-flows (Revenues and OPEX) can be said to be influenced by the changes in forecast scenarios. Therefore, affecting the final project indicators i.e. NPV values and the payback period of the project.

- *DEVEX*: The Development expenditures remain the same regardless of the active scenario; making it a static cash-flow. The total DEVEX involved within the project amounts to 0.5 Million EUR which is budgeted from 2016 - 2020. The distribution of DEVEX along the project timeline is plotted in Figure 9.5.

Figure 9.5: DEVEX distribution against project time horizon

- *CAPEX* : Change in the active scenario does not affect the capital expenditures for the port expansion. The financial model considers CAPEX to be a static component. The capital expenditures last for the duration of 10 years (2018 - 2020). The upfront investment for the Infrastructural CAPEX amounts to 350 Million EUR which is irreversible. The investment is plotted against the respective years in Figure 9.6.

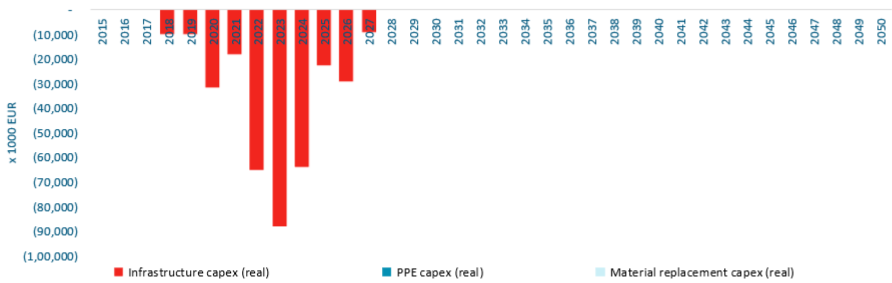


Figure 9.6: CAPEX distribution against project time horizon

- *OPEX* :
  The Operational Expenditures incurred by the port authority vary based on the active scenario chosen. Figure 4.5 shows that OPEX consists of two sub-components: Maintenance and General operational expenditures.
  - Maintenance OPEX:
    This sub-component is calculated as a percentage of the infrastructural CAPEX incurred by the port authority. Regardless of the active scenarios, maintenance OPEX remains the same. The underlying reason is that the scenarios are developed based on forecasted volumes and not the different possibilities of expansion. Hence it can be claimed that the existing model utilises maintenance OPEX as a static parameter.
  - General OPEX: This sub-components is calculated as a percentage of revenues gained during the project timeline. To be specific, the general OPEX is calculated as 45.23% of the revenues. The revenue earned through the project timeline is influenced by the volumes handled by the port. Thereby, it can be claimed, different scenarios can lead to different values of general OPEX. Thereby making this sub-component to be impacted by a change in volume. Through, Figure 9.7, it can be observed, the variation in OPEX values, calculated through the three different demand scenario.
  - Total OPEX:
    The total OPEX is the summation of maintenance and general OPEX. The maintenance OPEX is a static sub-component, while the general OPEX is a variable sub-component, resulting in total OPEX

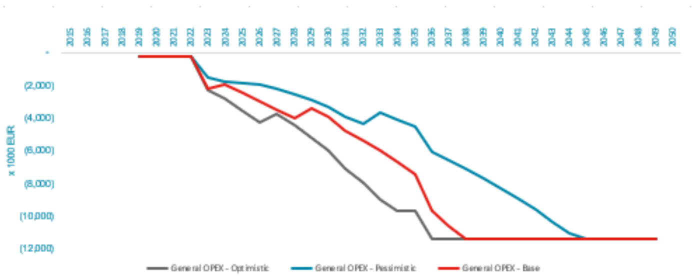


Figure 9.7: General OPEX based on scenario's against time

Changes in scenarios show variation in the calculated General OPEX. Through the figure, it can be observed that the general OPEX for the line plot for the optimistic scenario involves the greatest slope and the line plot for the pessimistic involves comparatively lesser slope. The optimistic scenario involves the fastest growth in forecasted volumes, thereby resulting in greatest general OPEX within the project timeline.

to be variable as well. Therefore, the calculated OPEX varies based on the scenario of forecasted volumes.

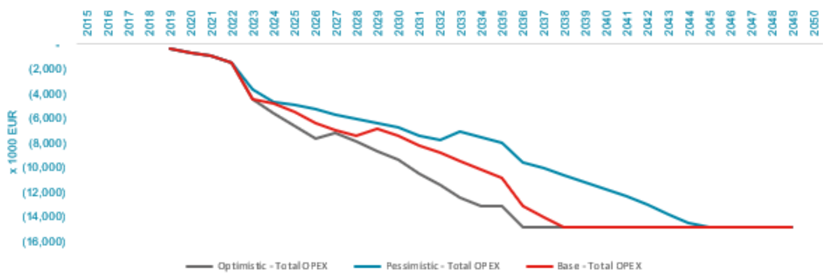


Figure 9.8: Total OPEX based on scenario's against time

The total OPEX reflects the same variation as shown by the sub-component of general OPEX. Contrasting the total OPEX for the three scenarios, it can be gathered that, in an optimistic scenario, the greatest magnitude of OPEX is involved in the earlier timeline of the project timeline.

- *Revenues* :
  This cash in-flow stream is built by four sub-components (refer Figure 4.5) which are port dues, cargo dues, fixed concession fees and variable concession fees. Within the existing financial model, the revenues are calculated based on the forecasted volumes. Therefore, the revenues are immensely affected by the chosen scenario forecasted volumes.
  - *Port Dues*:
    This sub-component of revenues is earned by the port authority based on the vessels forecast.The port dues are calculated based on the respective tariffs for the respective vessel sizes.
  - *Cargo Dues*:
    Cargo Dues are levied on the users of the African Port's facilities for the moving cargo. This sub-component is dependent on the forecasted volumes. The current financial model calculated this cash-inflow by using the three scenarios of volume forecast and the tariff to be levied by the port authority.
  - *Concession Fees*:
    - Fixed Concession Fees
      The fixed concession fees is a static sub-component for calculating revenue. Thus not influenced by yearly forecasted volumes. This is paid by the operator to the port authority This revenue is received per year based on an agreed rate signed within the contract.
    - *Variable Concession Fees*:
      Similar to the fixed concession fees, variable concession fees are also paid by the operator to

the port authority. However, the variable concession fee is dependent on the scenarios of the forecasted volumes. It is calculated based on an agreed amount of fee per TEU (unit EUR/TEU) for all the throughput volumes exceeding the currently forecasted volumes. Additionally, the port authority provides a discount on the unit fee rate when the future throughput volumes exceed a discount breakpoint.

Figure 9.9, show the revenue streams based on the three demand scenarios. The variation in revenues due to the three demand scenarios can be said to heavily influence the NPV. Considering revenues to be the only cash-inflow for the port authority, unprecedented changes in the future may result in different pay-off structures than what has been presently been anticipated.

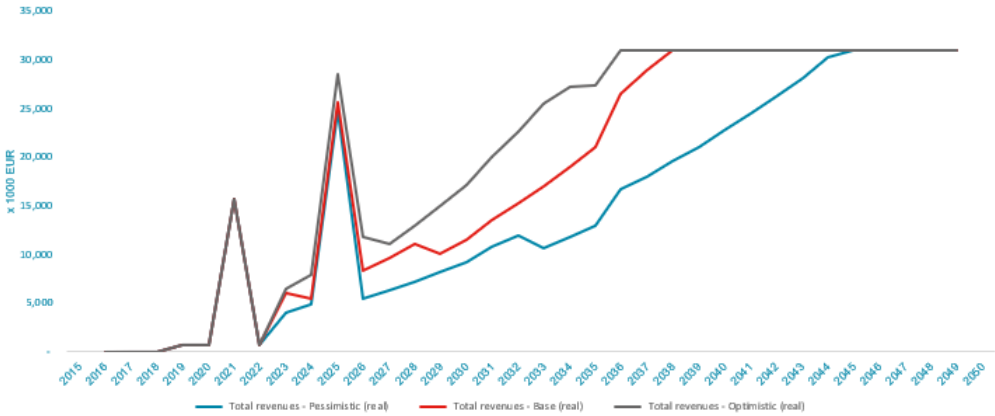


Figure 9.9: Total Revenues based on scenario's against time

10

APPENDIX-B

10.1. Conceptual Framework

This section presents the further explanation involved in the steps of the devised conceptual framework.

10.1.1. Real options in port industry

Figure 10.1, presents the types of real options present in the context of port infrastructures. These set of real options can allow the port authority to identify similar options in their projects.

Group	*Sub-group*	*Example*
Invest/grow	Scale up	• Invest in other lands (PoR International invests in the Port of Sohar in Oman and the Positra port project in India)
		• Invest in steel sheet-piles in anticipation of an increase in steel prices, for a future port expansion project
	Switch up	• Convert bulk terminal into container terminal and bulk cranes into container cranes (Waalhaven in PoR in 1960s)
		• Use general cargo quay for containers (Eemhaven in PoR in 1960s)
	Scope up	• Perform value added logistics in addition to container handling (third generation container ports)
		• Add real estate business to the core functions of the port
		• Design multifunctional port infrastructure (underground storage of CO2/LNG/reefer containers)
Defer/learn	Study/ start	• Carry out expansion in phases in response to anticipated growth of demand (Maasvlakte 2, PoR)
		• A chemical industry takes an option on a piece of land and exercises it if a chemical cluster develops close by, in order to pool resources
Disinvest/ shrink	Scale down	• Plan port expansion in phases; reassess in response to demand
		• Create an option for a client to terminate land lease in case their future demand for expansion space cannot be accommodated
	Switch down	• Limit port activity to transhipment due to inadequate road and rail infrastructure in the hinterland
		• Function as a 'spoke' port instead of a 'hub' port
	Scope down	• Concentrate on niche markets

Figure 10.1: Examples of Options in Port decisions (Source: Taneja et al.,2011)

10.1.2. Questionnaire to identify and operationalise options thinking

To identify the options present in the project, the port authority and consultants can ask the questions as tabulated in Table 10.1. These questions will allow for structuring and operationalising options thinking by the port authority and the consultants. These questions can be used by port authorities and consultants in the brainstorming session to develop further numerical ROA models.

Table 10.1: Identifying Real Options(Source: Taneja et al.,2010)

Option
Establishing Success Criteria
What is the success criterion for the project?
Reducing Uncertainty
What are the sources of uncertainty in this project?
Can you uncertainty be modeled/shaped?
Can more information about the project be gained by doing more research?
Can you hedge the risk?
Can the risks be transferred to other parties who are more capable?
Identify managerial Options
Where does the uncertainty stem from (market/private)?
Can the decision-making be phased?
Does the project consist of contingent decisions?
Will the project result in growth opportunities?
What are the actions to obtain or retain flexibility?
Identify operational options
Can the operations made more flexible?
Set up Decision Rules
What are the actions required to change the strategy?
What is the decision rule for changing the strategy?

10.2. GBM Solution

This section presents the solution obtained for the equation of the stochastic process. The stochastic differential equation cannot be directly applied for numerical solutions. Hence, the solution for throughput volumes at time T (denoted by V_T) is derived using the following steps. The Stochastic differential equation is as follows:
$dV_t = rV_t dt + \sigma V_t dZ_t$
In order to solve the above equation, $\ln V_t$ is considered on both sides of the equations. Through the Ito's Process and ln consideration the following intermediate equation is obtained:
$d\ln V_t = \frac{\partial \ln V_t}{\partial V_t} dV_t + \frac{1}{2}\frac{\partial^2 \ln V_t}{\partial V_t^2} dV_t^2$
$d\ln V_t = \frac{\partial \ln V_t}{\partial V_t} dV_t + \frac{1}{2}\frac{\partial^2 \ln V_t}{\partial V_t^2} dV_t^2$
$d\ln V_t = \frac{1}{V_t} dV_t - \frac{1}{2}\frac{1}{V_t^2} dV_t^2$
$d\ln V_t = \frac{1}{V_t}(rV_t dt + \sigma V_t dZ_t) - \frac{1}{2}\frac{1}{V_t^2}\sigma^2 V_t^2 dt$
The final result obtained from the Ito's Process is as follows:

$$d\ln V_t = rdt + \sigma dB_t - \frac{1}{2}\sigma^2 dt = \left(r - 0.5\sigma^2\right) dt + \sigma dZ_t \tag{10.1}$$

Rewriting the above equation, the following is obtained:

$$d\ln V_t = \left(r - 0.5\sigma^2\right) dt + \sigma dZ_t \tag{10.2}$$

Taking an integral with the limits on time t ranging from 0 to T. The following steps are obtained:
$\int_0^T d\ln V_t = \int_0^T \left(r - 0.5\sigma^2\right) dt + \int_0^T \sigma dZ_t$
$\ln V_T - \ln V_0 = \left(r - 0.5\sigma^2\right) \int_0^T dt + \sigma \int_0^T dZ_t$
$\ln \frac{V_T}{V_0} = \left(r - 0.5\sigma^2\right) T + \sigma Z_T$
$\frac{V_T}{V_0} = e^{\left(r-0.5\sigma^2\right)T + \sigma Z_T}$
$V_T = V_0 e^{\left(r-0.5\sigma^2\right)T + \sigma Z_T}$
$V_T = e^{\ln V_0 + \left(r-0.5\sigma^2\right)T + \sigma Z_T}$
dZ_T is the weiner increment which is substituted with $\varepsilon\sqrt{dt}$ and the following is obtained:
$V_T = V_t e^{\left(r-0.5\sigma^2\right)(T-t) + \sigma\sqrt{T-t}\varepsilon}$
The final solution for the standard differential equation of GBM is as follows:

$$V_{t+\Delta t} = V_t e^{\left(r-0.5\sigma^2\right)\Delta t + \sigma\sqrt{\Delta t}\varepsilon} \tag{10.3}$$

It is this equation which is used for estimating future possibilities in the numerical solution.

10.3. Option Structure

This section further visualises the option structure using option tree for the flexible strategies wherein it is either HQHC or FQHC which are the first expansion strategies which are then sequentially followed with greater increments of magnitude.

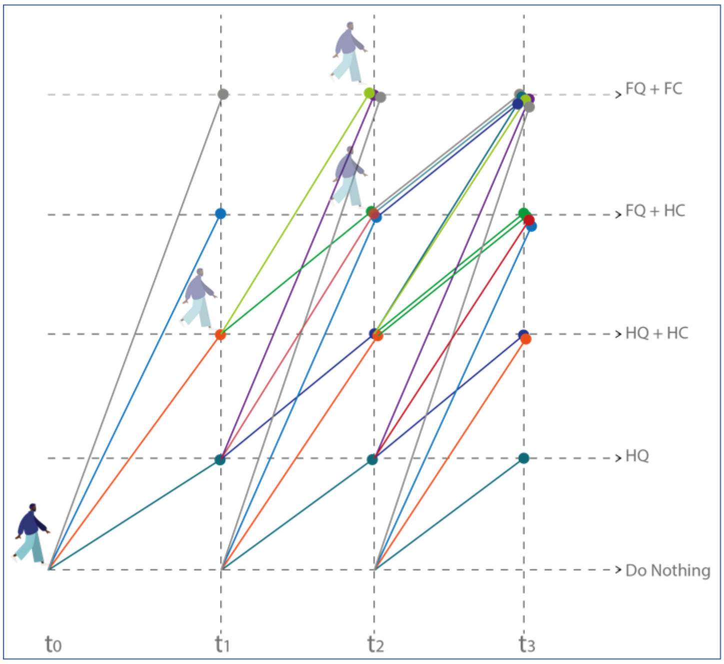


Figure 10.2: HQHC Flex Option Tree

At each discrete time t_i the decision maker has the option to first expand by HQHC. At subsequent time moments the decision maker can choose to expand by either FQHC FQFC or do nothing. Such an expansion structure allows for flexibility on the project.

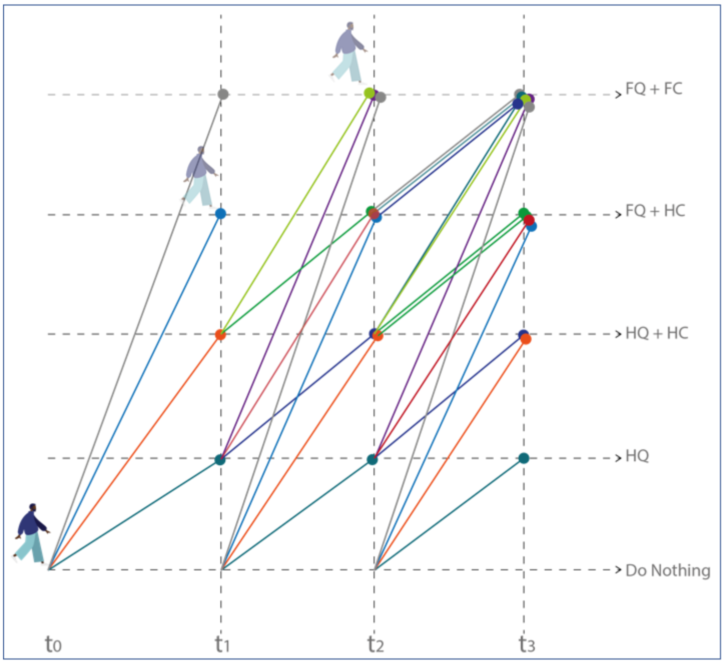


Figure 10.3: FQHC Flex Option Tree

At each discrete time t_i the decision maker has the option to first expand by FQHC. At subsequent time moments the decision maker can choose to expand by either FQFC or do nothing. Such an expansion structure allows for flexibility on the project.

11

APPENDIX-Results

11.1. GBM Statistics

This section highlights the results obtained from the operationalisation of the stochastic process of GBM to the case. These results are obtained through the application of GBM followed by Monte-Carlo simulations for 2500 runs.

Table 11.1: Complete Statistics for the output of GBM and Monte-Carlo Simulations

Description	**Unit**	**Years**						
		2020	2025	2030	2035	2040	2045	2050
Mean	000 TEU	283.05	407.64	579.46	829.57	1189.93	1707.65	2451.12
Median	000 TEU	278.22	380.39	518.43	710.56	955.77	1310.4	1814.06
Standard deviation	000 TEU	55.47149	153.6489	297.4355	523.2505	868.9899	1427.304	2331.708
Skewness		0.672176	1.239403	1.957676	2.361349	2.610531	3.062759	3.56396
Kurtosis		0.866589	2.674862	7.813071	10.63388	11.55874	15.54923	21.76814
P5 value	000 TEU	201.2642	212.2916	240.9394	278.4637	351.78	413.2944	492.0712
P25 value	000 TEU	245.1835	298.7077	373.6302	475.7035	632.7487	819.0208	1038.712
P75 value	000 TEU	315.0522	486.3373	708.4563	1029.539	1495.907	2133.254	3039.269
P95 value	000 TEU	383.5138	691.595	1115.635	1779.996	2738.315	4259.536	6367.121
Maximum value	000 TEU	533.6	1288.15	3299.38	5976.91	8669	15202.17	28174.94
Minimum value	000 TEU	139.92	103.34	97.3	91.22	121.1	101.95	160.05

11.2. HQ

Within this section the results for the option of HQ has been described. These results have been obtained from the numerical model which was implemented on the case of African Port.

11.2.1. Summary of Statistics observed for different time moments for HQ

Table 11.2: Summary of statistics for NPV distributions observed for different time for HQ

Description	2020	2021	2022	2023
Mean	40.2595	39.0456	37.53701	36.36655
Standard Error	0.675435	0.661147	0.62584	0.609643
Median	50	49	48	46
Mode	54	52	49	47
Standard Deviation	33.77849	33.05735	31.28575	30.47607
Sample Variance	1140.987	1092.789	978.798	928.7911
Kurtosis	10.75194	11.60278	7.441968	7.99539
Skewness	-1.5297	-1.57478	-2.34539	-2.43839
Range	562	561	271	269
Minimum	-162	-162	-161	-160
Maximum	400	399	110	109
P(NPV>0)	0.89996	0.898719	0.9012	0.9024

11.2.2. Tabulation of different statistical values of NPV for HQ

Mean		Second Moment of Investment NA
First Moment of Investment	2,020	40,257
	2,021	39,057
	2,022	37,677
	2,023	36,513
	2,024	34,617

P25		Second Moment of Investment NA
First Moment of Investment	2,020	33,023
	2,021	32,883
	2,022	33,072
	2,023	33,285
	2,024	32,723

P50		Second Moment of Investment NA
First Moment of Investment	2,020	50,290
	2,021	49,385
	2,022	47,750
	2,023	46,019
	2,024	43,579

P75		Second Moment of Investment NA
First Moment of Investment	2,020	56,576
	2,021	53,827
	2,022	50,827
	2,023	48,640
	2,024	46,001

Figure 11.1: Relevant statistics figures for the NPV distributions for HQ Option

11.3. HQHC

Within this section the results for the option of HQHC has been described. These results have been obtained from the numerical model which was implemented on the case of African Port.

11.3.1. Summary of Statistics observed for different time moments for HQHC

11.3.2. Tabulation of different statistical values of NPV for HQHC

Figure 11.2: Relevant statistics figures for the NPV distributions for HQ Option

Table 11.3: Summary of statistics for NPV distributions observed for different time for HQHC

Description	2020	2021	2022	2023
Mean	35.507	32.79888	29.42143	27.03998
Standard Error	1.76185	1.726516	1.693924	1.646872
Median	60	58	54	52
Mode	84	92	80	75
Standard Deviation	88.11012	86.34305	84.71313	82.36005
Sample Variance	7763.394	7455.122	7176.315	6783.178
Kurtosis	1.552684	1.700471	1.840049	2.046523
Skewness	-1.12379	-1.16811	-1.20208	-1.25431
Range	807	805	802	797
Minimum	-327	-328	-328	-326
Maximum	480	477	474	471
P(NPV>0)	0.727491	0.726181	0.7204	0.7208

11.4. FQHC

Within this section the results for the option of FQHC has been described. These results have been obtained from the numerical model which was implemented on the case of African Port.

Table 11.4: Summary of statistics for NPV distributions observed for different time for FQHC

Description	2020	2021	2022	2023
Description	2020	2021	2022	2023
Mean	-17.4919	-21.8289	-25.4275	-29.4275
Standard Error	2.358717	2.304315	3.12401	3.046374
Median	9.339	6.365	6.255	5.85
Standard Deviation	117.9594	115.2388	116.244	119.689
Sample Variance	13914.42	13279.98	13512.67	14325.46
Kurtosis	0.676735	0.762778	0.761526	0.759632
Skewness	-0.96005	-0.9989	-0.9802	-0.9623
Minimum	-489.926	-490.868	-488.25	-492.699
Maximum	257.997	255.835	254.698	254.554
P(NPV>0)	0.531813	0.520016	0.5113	0.5103

11.5. FQFC

Within this section the results for the option of FQFC has been described. These results have been obtained from the numerical model which was implemented on the case of African Port.

11.5.1. Tabulation of different statistical values of NPV for FQFC

Table 11.5: Summary of statistics for NPV distributions observed for different time for FQFC

Description	2020	2021	2022	2023
Mean	-57.9216	-63.0852	-66.6837	-62.1795
Standard Error	3.838887	3.787018	3.713138	3.944306
Median	-31	-36	-37	-31
Mode	85	147	72	-81
Standard Deviation	191.9828	189.3888	185.694	197.2547
Sample Variance	36857.38	35868.1	34482.27	38909.43
Kurtosis	-0.51954	-0.50808	-0.48696	-0.59929
Skewness	-0.43821	-0.46365	-0.49746	-0.46168
Range	1137	1135	1128	941
Minimum	-615	-617	-614	-630
Maximum	522	518	514	311
P(NPV>0)	0.444978	0.43715	0.4308	0.4492

Mean		Second Moment of Investment NA
First Moment of Investment	2,020	(57,919)
	2,021	(63,082)
	2,022	(66,685)
	2,023	(62,055)
	2,024	(67,392)

P25		Second Moment of Investment NA
First Moment of Investment	2,020	(1,97,167)
	2,021	(2,00,676)
	2,022	(2,01,728)
	2,023	(2,08,949)
	2,024	(2,08,815)

P50		Second Moment of Investment NA
First Moment of Investment	2,020	(30,719)
	2,021	(36,038)
	2,022	(37,162)
	2,023	(30,769)
	2,024	(34,059)

P75		Second Moment of Investment NA
First Moment of Investment	2,020	93325
	2,021	87085
	2,022	82979
	2,023	100038
	2,024	88,110

Figure 11.3: Relevant statistics figures for the NPV distributions for FQFC Option

11.6. HQHQHC Flex

Within this section the results for the option of HQHQHC has been described. These results have been obtained from the numerical model which was implemented on the case of African Port.

Table 11.6: Summary of statistics for NPV distributions observed for different time for HQHQHC

Description	2020 & 2027	2020 & 2028	2020 & 2029	2020 & 2030	2021 & 2027	2021 & 2028	2021 & 2029	2021 & 2030	2022 & 2027	2022 & 2028
Mean	30.297	28.161	25.772	22.686	28.407	26.278	23.863	20.752	27.087	24.948
Standard Error	1.648	1.606	1.562	1.511	1.633	1.592	1.549	1.497	1.616	1.575
Median	58	56	54	50	56	55	52	49	55	53
Mode	75	70	65	59	72	67	62	56	70	65
Standard Deviation	82.365	80.292	78.098	75.513	81.656	79.593	77.410	74.840	80.791	78.731
Sample Variance	6784.046	6446.869	6099.250	5702.172	6667.733	6335.120	5992.311	5600.985	6527.143	6198.550
Kurtosis	1.861	2.056	2.272	2.540	1.918	2.119	2.337	2.613	1.986	2.190
Skewness	-1.359	-1.416	-1.475	-1.542	-1.379	-1.436	-1.496	-1.564	-1.399	-1.457
Range	514	504	495	484	510	501	490	481	505	496
Minimum	-325	-323	-321	-318	-326	-324	-321	-319	-325	-323
Maximum	189	181	174	166	184	177	169	162	180	173
P(NPV >0)	0.7332	0.734	0.7372	0.7384	0.732	0.7332	0.7332	0.7352	0.7312	0.7328

Description	2022 & 2029	2022 & 2030	2023 & 2027	2023 & 2028	2023 & 2029	2023 & 2030	2024 & 2027	2024 & 2028	2024 & 2029	2024 & 2030
Mean	22.525	19.424	25.797	23.661	21.239	18.124	23.894	21.746	19.336	16.234
Standard Error	1.532	1.480	1.598	1.557	1.514	1.464	1.585	1.545	1.528	1.451
Median	51	47	54	52	50	46	52	50	47	44
Mode	60	54	68	63	58	52	65	61	58	50
Standard Deviation	76.577	74.008	79.884	77.846	75.692	73.161	79.242	77.215	76.395	72.529
Sample Variance	5864.014	5477.196	6381.531	6060.070	5729.324	5352.463	6279.222	5962.136	5836.249	5260.504
Kurtosis	2.408	2.692	2.053	2.261	2.484	2.777	2.095	2.307	2.368	2.834
Skewness	-1.516	-1.586	-1.419	-1.477	-1.537	-1.609	-1.428	-1.487	-1.502	-1.620
Range	486	476	501	492	482	472	498	489	485	469
Minimum	-320	-318	-324	-322	-319	-317	-324	-322	-322	-317
Maximum	166	158	177	170	163	155	174	167	163	152
P(NPV >0)	0.7324	0.734	0.7304	0.732	0.7316	0.7312	0.7236	0.7268	0.7188	0.7284

11.6.1. Tabulation of different statistical values of NPV for HQHQHC Flex

Mean	Second Moment of Investment 2,027	2,028	2,029	2,030
First Moment of Investment 2,020	30,469	28,345	25,942	22,853
2,021	28,594	26,457	24,040	20,934
2,022	27,267	25,129	22,710	19,601
2,023	25,980	23,841	21,421	18,308
2,024	24,080	21,940	19,519	16,402

P50	Second Moment of Investment 2,027	2,028	2,029	2,030
First Moment of Investment 2,020	57,826	56,456	53,954	50,199
2,021	56,289	54,843	52,267	48,930
2,022	55,304	53,342	51,187	47,500
2,023	53,832	52,016	49,700	46,067
2,024	51,643	49,756	47,706	43,802

P25	Second Moment of Investment 2,027	2,028	2,029	2,030
First Moment of Investment 2,020	(6,750)	(6,191)	(6,159)	(5,868)
2,021	(7,614)	(7,829)	(7,496)	(7,154)
2,022	(8,255)	(8,499)	(7,933)	(7,553)
2,023	(8,842)	(8,626)	(8,541)	(8,069)
2,024	(9,884)	(9,386)	(9,309)	(8,832)

P75	Second Moment of Investment 2,027	2,028	2,029	2,030
First Moment of Investment 2,020	80,688	76,236	71,113	64,892
2,021	78,050	73,294	67,900	61,859
2,022	75,907	70,918	65,679	59,470
2,023	73,998	68,820	63,461	57,426
2,024	71,483	66,271	60,907	54,803

Figure 11.4: Relevant statistics figures for the NPV distributions for HQHQHC Flex Option

11.7. HQFQHC Flex

Within this section the results for the flexible option of HQFQHC has been described. These results have been obtained from the numerical model which was implemented on the case of African Port.

Table 11.7: Summary of statistics for NPV distributions observed for different time for HQFQHC

Description	2020 & 2027	2020 & 2028	2020 & 2029	2020 & 2030	2021 & 2027	2021 & 2028	2021 & 2029	2021 & 2030	2022 & 2027	2022 & 2028	2022 & 2029	2022 & 2030	2023 & 2027	2023 & 2028	2023 & 2029	2023 & 2030
Mean	-28.7283	-32.4142	-36.9368	-41.9556	-31.3533	-35.0752	-39.6074	-44.6647	-32.946	-36.6691	-41.2109	-46.2761	-34.2701	-37.9908	-42.5262	-47.5846
Standard Error	2.277383	2.209516	2.129965	2.044164	2.259738	2.192273	2.112981	2.027611	2.236477	2.169791	2.090693	2.006001	2.2192	2.152332	2.073978	1.989195
Median	4	3	-1	-6	2	0	-4	-8	0	-2	-6	-10	-1	-4	-7	-11
Mode	39	35	23	11	38	30	21	8	34	25	16	6	34	24	14	4
Standard Deviation	113.8464	110.4537	106.4769	102.1878	112.9643	109.5917	105.6279	101.3603	111.8015	108.4679	104.5137	100.28	110.9378	107.5951	103.6781	99.43984
Sample Variance	12961	12200.02	11337.34	10442.34	12760.93	12010.35	11157.26	10273.9	12499.58	11765.28	10923.12	10056.07	12307.19	11576.7	10749.16	9888.282
Kurtosis	0.667742	0.807112	0.989509	1.202071	0.698096	0.841399	1.025273	1.242947	0.73524	0.880611	1.070492	1.289553	0.757156	0.906165	1.096561	1.321366
Skewness	-1.03114	-1.08442	-1.14772	-1.21457	-1.04527	-1.09921	-1.16269	-1.23076	-1.06073	-1.11494	-1.17945	-1.24782	-1.06966	-1.12491	-1.1892	-1.25879
Range	641	626	610	594	636	621	605	589	629	614	599	582	625	611	594	578
Minimum	-454	-451	-448	-445	-455	-452	-449	-446	-454	-451	-448	-445	-453	-451	-447	-444
Maximum	187	175	162	149	181	169	156	143	175	163	151	137	172	160	147	134
P(NPV>0)	0.5112	0.506	0.4924	0.4704	0.5036	0.498	0.4852	0.4564	0.5	0.4924	0.4792	0.446	0.496	0.4868	0.472	0.4324

11.7.1. Tabulation of different statistical values of NPV for HQFQHC Flex

Mean	Second Moment of Investment 2,027	2,028	2,029	2,030
First Moment of Investment 2,020	(28,526)	(32,215)	(36,722)	(41,770)
2,021	(31,156)	(34,874)	(39,409)	(44,484)
2,022	(32,744)	(36,465)	(41,001)	(46,079)
2,023	(34,055)	(37,779)	(42,317)	(47,397)
2,024	(35,979)	(39,706)	(44,246)	(49,328)

P25	Second Moment of Investment 2,027	2,028	2,029	2,030
First Moment of Investment 2,020	(92,087)	(91,959)	(91,462)	(91,656)
2,021	(94,321)	(94,180)	(94,083)	(93,568)
2,022	(95,544)	(94,971)	(94,536)	(94,092)
2,023	(96,242)	(96,033)	(95,407)	(95,102)
2,024	(96,990)	(97,019)	(96,298)	(96,271)

P50	Second Moment of Investment 2,027	2,028	2,029	2,030
First Moment of Investment 2,020	4,234	2,508	(1,431)	(5,587)
2,021	1,757	(58)	(3,967)	(8,209)
2,022	405	(1,799)	(5,682)	(9,927)
2,023	(952)	(3,545)	(6,914)	(10,764)
2,024	(3,198)	(5,282)	(8,809)	(12,463)

P75	Second Moment of Investment 2,027	2,028	2,029	2,030
First Moment of Investment 2,020	51,665	42,899	33,165	23,575
2,021	47,867	38,668	29,362	19,599
2,022	44,487	35630	26,549	16,303
2,023	42,425	33,713	24,567	14,344
2,024	39,917	31,289	21,883	11,813

Figure 11.5: Relevant statistics figures for the NPV distributions for HQFQHC Option

11.8. HQFQFC Flex

Within this section the results for the flexible option of HQFQFC has been described. These results have been obtained from the numerical model which was implemented on the case of African Port.

Table 11.8: Summary of statistics for NPV distributions observed for different time for HQFQFC

Description	2020 & 2027	2020 & 2028	2020 & 2029	2021 & 2027	2021 & 2028	2021 & 2029	2022 & 2027	2022 & 2028	2022 & 2029	2023 & 2027	2023 & 2028	2023 & 2029
Mean	-66.55	-69.85	-73.91	-69.89	-73.22	-77.32	-71.61	-74.94	-79.04	-73.43	-76.76	-80.87
Standard Error	3.70	3.63	3.55	3.68	3.61	3.53	3.65	3.59	3.50	3.62	3.55	3.46
Median	-33.00	-33.00	-34.00	-36.00	-36.00	-37.00	-37.00	-38.00	-37.00	-39.00	-39.00	-39.00
Mode	90.00	74.00	58.00	-1.00	68.00	50.00	73.00	64.00	41.00	70.00	52.00	39.00
Standard Deviation	185.16	181.69	177.40	184.15	180.70	176.43	182.71	179.28	175.02	180.85	177.42	173.21
Sample Variance	34286.05	33010.21	31470.03	33911.12	32652.70	31128.58	33382.76	32139.54	30633.45	32707.72	31479.37	30001.95
Kurtosis	-0.49	-0.46	-0.41	-0.49	-0.45	-0.40	-0.48	-0.44	-0.39	-0.47	-0.43	-0.38
Skewness	-0.54	-0.58	-0.62	-0.55	-0.59	-0.63	-0.56	-0.59	-0.64	-0.57	-0.60	-0.65
Range	900.00	885.00	869.00	894.00	880.00	864.00	886.00	871.00	856.00	875.00	862.00	846.00
Minimum	-611.00	-609.00	-609.00	-612.00	-611.00	-611.00	-611.00	-610.00	-610.00	-609.00	-609.00	-609.00
Maximum	289.00	276.00	260.00	282.00	269.00	253.00	275.00	261.00	246.00	266.00	253.00	237.00
P(NPV>0)	0.4384	0.4364	0.4352	0.432	0.4328	0.4284	0.428	0.4292	0.4256	0.428	0.4244	0.422

11.8.1. Tabulation of different statistical values of NPV for HQFQFC Flex

		Second Moment of Investment			
Mean		2,027	2,028	2,029	2,030
First Moment of Investment	2,020	(66,320)	(69,615)	(73,677)	(78,364)
	2,021	(69,660)	(72,996)	(77,099)	(81,827)
	2,022	(71,379)	(74,717)	(78,821)	(83,551)
	2,023	(73,191)	(76,530)	(80,636)	(85,368)

		Second Moment of Investment			
P50		2,027	2,028	2,029	2,030
First Moment of Investment	2,020	(32,713)	(33,011)	(33,729)	(34,195)
	2,021	(36,291)	(36,367)	(36,804)	(37,374)
	2,022	(37,089)	(37,573)	(37,392)	(38,302)
	2,023	(39,204)	(38,909)	(38,676)	(40,665)

		Second Moment of Investment			
P25		2,027	2,028	2,029	2,030
First Moment of Investment	2,020	(1,99,952)	(1,99,280)	(1,99,037)	(2,00,040)
	2,021	(2,01,944)	(2,02,158)	(2,01,519)	(2,02,325)
	2,022	(2,03,320)	(2,02,925)	(2,02,339)	(2,02,366)
	2,023	(2,02,413)	(2,02,224)	(2,01,462)	(2,02,828)

		Second Moment of Investment			
P75		2,027	2,028	2,029	2,030
First Moment of Investment	2,020	82,099	73,872	63,613	64,540
	2,021	77,396	68,703	58,909	48,650
	2,022	74,175	65546	55,705	45,789
	2,023	69,943	62,500	51,973	41,040

Figure 11.6: Relevant statistics figures for the NPV distributions for HQFQFC Option

11.9. HQHCFQHC Flex

Within this section the results for the flexible option of HQHCFQHC has been described. These results have been obtained from the numerical model which was implemented on the case of African Port.

Table 11.9: Summary of statistics for NPV distributions observed for different time for HQHCFQHC

Description	2020 & 2039	2020 & 2040	2020 & 2041	2020 & 2042	2021 & 2039	2021 & 2040	2021 & 2041	2021 & 2042	2022 & 2039	2022 & 2040	2022 & 2041	2022 & 2042	2023 & 2039	2023 & 2040	2023 & 2041	2023 & 2042
Mean	-30.6757	-31.4566	-32.3591	-33.3295	-34.2287	-35.0184	-35.914	-36.9028	-37.6537	-38.4406	-39.3708	-40.3123	-37.6537	-38.4406	-39.3708	-40.3123
Standard Error	2.13286	2.095857	2.059791	2.025342	2.096873	2.059878	2.023823	1.989247	2.065156	2.027832	1.992181	1.957136	2.065156	2.027832	1.992181	1.957136
Median	0	-1	-2	-4	-4	-5	-6	-7	-7	-8	-9	-11	-7	-8	-9	-11
Mode	36	28	26	24	33	25	24	27	24	22	20	18	24	22	20	18
Standard Deviation	106.6643	104.8138	103.0102	101.2874	104.8646	103.0145	101.2114	99.48225	103.2785	101.4119	99.60904	97.87639	103.2785	101.4119	99.60904	97.87639
Sample Variance	11377.28	10985.93	10611.09	10259.13	10996.59	10611.99	10243.75	9896.717	10666.44	10284.37	9921.96	9579.787	10666.44	10284.37	9921.96	9579.787
Kurtosis	1.080073	1.147069	1.209022	1.260765	1.175881	1.248241	1.313766	1.371108	1.260414	1.338996	1.411217	1.473335	1.260414	1.338996	1.411217	1.473335
Skewness	-1.08026	-1.0935	-1.10378	-1.1111	-1.11479	-1.12946	-1.14036	-1.14892	-1.13928	-1.15509	-1.1673	-1.17702	-1.13928	-1.15509	-1.1673	-1.17702
Range	883	876	870	863	881	874	868	861	878	871	865	858	878	871	865	858
Minimum	-440	-437	-434	-431	-441	-438	-435	-432	-442	-439	-436	-433	-442	-439	-436	-433
Maximum	443	439	436	432	440	436	433	429	436	432	429	425	436	432	429	425
P(NPV>0)	0.4984	0.491397	0.4868	0.4784	0.482193	0.48	0.472	0.4656	0.4724	0.464	0.4568	0.446	0.4724	0.464	0.4568	0.446

11.9.1. Tabulation of different statistical values of NPV for HQHCFQHC Flex

Mean		Second Moment of Investment			
		2,039	2,040	2,041	2,042
First Moment of Investment	2,020	(30,675)	(31,459)	(32,354)	(33,341)
	2,021	(34,236)	(35,019)	(35,914)	(36,901)
	2,022	(37,647)	(38,430)	(39,324)	(40,311)
	2,023	(40,346)	(41,128)	(41,000)	(43,009)

P50		Second Moment of Investment			
		2,039	2,040	2,041	2,042
First Moment of Investment	2,020	228	(1,068)	(2,432)	(4,064)
	2,021	(3,690)	(4,744)	(6,080)	(7,296)
	2,022	(7,035)	(8,161)	(9,274)	(10,770)
	2,023	(8,475)	(9,945)	(9,165)	(12,953)

P25		Second Moment of Investment			
		2,039	2,040	2,041	2,042
First Moment of Investment	2,020	(82,816)	(82,758)	(82,557)	(82,797)
	2,021	(84,776)	(84,304)	(84,442)	(83,564)
	2,022	(87,524)	(85,704)	(85,959)	(84,983)
	2,023	(88,415)	(86,470)	(82,672)	(86,197)

P75		Second Moment of Investment			
		2,039	2,040	2,041	2,042
First Moment of Investment	2,020	42,776	40,420	38,354	35,929
	2,021	36,476	34,178	32,084	29,749
	2,022	31,027	28662	26,194	24,095
	2,023	24,889	22,909	19,736	18,168

Figure 11.7: Relevant statistics figures for the NPV distributions for HQHCFQHC Option

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