Choosing the Optimal Mode of Operation for Marine Container Terminals

(Public Version)

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CONFIDENTIALITY

The summary of this thesis is public. The rest of this thesis is to be treated as confidential until: October, 2009

Preface and Acknowledgement

This report is the final result of the research project undertaken in order to obtain the degree of Master of Science at the faculty of Technology, Policy and Management of Delft University of Technology. The subject for the thesis was offered by the section of system engineering, and the work has been carried out at APM Terminals.

The aim of this research is to improve an existing model which is used as tool in APM Terminals to support the decision on choosing an optimal mode of operation for future terminals.

First of all my thanks go to my graduation committee: Prof. Dr. Ir. A. Verbraeck who provided overall guidance of my work on this thesis, Dr. Ir. C. Versteegt who helped me on a day to day basis, Drs. J.H.R. van Duin and Ir. M. Fumarola for their kind cooperation, enthusiasm and feedback on this research project.

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Last but not least, I would give my best gratitude to my family and my girlfriend Xin for the mental support and all the efforts to cheer me up now and then.

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Abstract

In the last four decades the container as an essential part of a unit load-concept has achieved undoubted importance in international sea freight transportation. With ever increasing containerization the numbers of seaport container terminals and competition among them have become quite remarkable. APM Terminals is one of the world's largest operators of container terminals with over 50 container terminals spanning 31 countries and five continents. In order to stand in the competition, APMT is under the pressure to build more new terminals around the world. Whether to choose human-based or automated mode of operation in new terminals has become an intractable question for APMT's policy maker. Currently, there is a prototype of a tool called Business Model, which can help terminal designers to decide which mode of operation is to be preferred. However, there are some limitations in the existing model. Thus, in this research, we will discuss how the accuracy and usability of the existing Business Model can be improved.

Executive summary

Driven by the trend towards globalization of the economy, world trade volumes have increased dramatically during the last decade. Today, maritime cargo transportation has become the predominant transportation mode in international trade. The increasing number of container shipments causes higher demands on marine container terminals. It is observed that existing and newly planned terminals are trying to attract as much volume as they can handle, which classifies the container handling sector as very competitive. The competitive advantages for a terminal operator are attributed to a rapid turnover of containers and to the cost of the transshipment process itself. How to achieve those competitive advantages by designing terminals in a proper way is a problem faced by all terminal operators. Furthermore, the selection of a mode of operation is considered as the most important decision during the design process of container terminals by the experts in this domain. On the other hand, there is little knowledge on automated container terminal gained by terminal operators while such strategies are more and more seen as promising alternatives compared to manual operations. It can also be observed that a number of terminals are developing new sites into automated terminals, starting from scratch. Therefore, terminal designers really need to be supported by a tool which considers automated solutions to help them select the mode of operation.

The Business Model is such a tool used to support choosing the mode of operation by calculating the investment cost and operational cost for all modes of operation. The model was first released in 2007. The objective of this research is extending the old version of the Business Model to increase the accuracy and the usability of the model. That was done in this research by adding calculations and new functionalities such as bottleneck analysis, sensitivity analysis and some graphical views. Those tasks are identified through a stakeholder analysis and a requirements analysis, and subsequently implemented in the Business Model. The results of bottleneck analysis provide an induction of the maximum terminal capacity given a certain amount of land and quay length. Through the sensitivity analysis, we identified the sensitive parameters toward the total cost of employing a mode of operation. The impacts of the changes of those parameters are shown in graphs. We also propose to refine the input parameters.

The new version of the Business Model was used by Maasvlakte II team. The result of the Business Model was compared with the relevant result from a simulation model. The comparison shows that the accuracy of the Business Model is at a comparable level as that of the simulation model, since the results provided from two sources are quite close. Finally, the improvement is evaluated by interviewing domain experts. It is concluded that the accuracy of the calculation on each mode of operation is improved; evidence for that is that the model can now be used to calculate the exact number of the required equipment during the planning. However, the comparison of modes of operation stays accurate. We also found from the evaluation that the new functionalities are not easy to use without the help of experienced users or experts. Since the user interface for the new functionality can not be simplified any further, training is needed to make optimal use of it and to obtain the resulting benefits from it. However, the overall usability of the model is improved by making better interface and graphic views.

Recommendations and future research are identified at the end of this research. We proposed to involve simulation when planning a new terminal, because there are lots of dynamic consequences in real terminal operation, which can not be addressed by a static study. We also suggest establishing a business intelligence system, by which historic data can be stored and used to produce knowledge. That knowledge can be used in future terminal designs. With respect to improve the usability of the model, we suggest adding additional considerations to the model, such as measurement of unemployment and safety issues. In order to improve the interaction between the Business Model and the Financial Model, we suggest to link between these two models. Linking the two models could be a long-term task, but at the initial stage, we propose to simplify the interaction between these two models by using standardized input and output sheets, which will be beneficial both in saving time of input and output and in keeping the integrity of the output data.

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Glossary of Economic Terms

All of the economic terms used in this research are referred from Eschenbach' book (Eschenbach 1989).

Present value (PV): The value on a given date of a future payment or series of future payments, discounted to reflect the time value of money and other factors such as investment risk.

Net present value (NPV): The total present value (PV) of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects.

Internal rate of return (IRR): An indicator of the efficiency of an investment, as opposed to net present value (NPV), which indicates value or magnitude.

Payback period: The period of time required for the return on an investment to "repay" the sum of the original investment.

Capital expenditure (CAPEX): The costs incurred on the purchase of land, buildings, construction and equipment to be used in the production of goods or the rendering of services.

Operational expenditure (OPEX): An on-going cost for running a product, business, or system. OPEX includes the cost of workers and facility expenses such as rent and utilities.

Depreciation: An asset's first cost or value does not disappear in the first year; rather, it is used up over the asset's life. This "using up" is a cost to the firm that is recognized through depreciation.

First Cost (FC): expense to build or to buy and install equipment.

Recovery period (N): the life for computing depreciation. It is the items' useful life for straight-line, declining balance and sum-of-the years'-digits depreciation. It is also referred as Life span of machine or land in the Business Model.

Salvage value(S): Receipt at project termination for sale or transfer of the equipment. It is called residual value in the Business Model.

Straight-line depreciation: Method that has equal annual depreciation. The rate of depreciation is constant at 1/N per year. The amount of depreciation is constant as well.

Definitions

Modal split: Distribution of cargo over transport modes (truck, train, barge).

Towage: Charge for the services of tugs assisting a ship in ports.

Transshipment: A distribution method whereby containers are moved between large mother ships and small feeder vessels, or between equally large ships sailing north-south (Europe-Africa) and east-west (Asia-Europe) routes. Transshipment can also mean the transfer of cargo from one vessel to another, e.g. from sea-going bulk vessels to inland barges or vice versa.

Twenty Feet Equivalent Unit (TEU): Container size standard of twenty feet. Two twenty-foot containers (TEUs) equal one Forty Feet Equivalent Unit (FEU). Container vessel capacity and port throughput capacity are frequently referred to in TEUs or FEUs.

Dwell time: The period during which a container remains stored in terminal.

1 Introduction

1.1 Trends of containerization

“Containers came into the market for international conveyance of sea freight almost five decades ago. They may be regarded as well accepted and they continue to achieve even more acceptance due to the fact that containers are the foundation for a unit-load-concept. Containers are relatively uniform boxes whose contents do not have to be unpacked at each point of transfer. They have been designed for easy and fast handling of freight. Besides the advantages for the discharge and loading process, the standardization of metal boxes provides many advantages for the customers, as there are protections against weather and pilferage, and improved and simplified scheduling and controlling, resulting in a profitable physical flow of cargo (Steenken, 2004).” In the present container shipping industry, the size of containers is standardized as one which is twenty feet (20’) long (the length of a short container). Other containers are measured by measured by means of these containers, i.e., in twenty feet equivalent units (TEU) (e.g., 40’ and 45’ containers represent 2 TEU).

“The first regular sea container service began about 1961 with an international container service between the US East Coast and points in the Caribbean, Central and South America. The breakthrough after a slow start was achieved with large investments in specially designed ships, adapted seaport terminals with suitable equipment, and availability (purchase or leasing) of containers”. [1]

1.1.1 Increase in the scale of maritime shipping

Containerization has revolutionized cargo shipping. “It is anticipated that the growth in containerized trade continues as more and more cargo are transferred from break-bulk to containers (Ryan, 1998).” An international containerization market analysis shows that in 1995 9.2 million TEU were in circulation. The container fleet had almost doubled in ten years from a size of 4.9 million TEU in 1985. Figure 1-1 shows the container turnover for the ten largest seaport terminals in the world from 1993 to 2002 (Boyes, 1994; 1997).

At present, approximately 90% of non-bulk cargo worldwide moves by containers stacked on transport ships; 26% of all containers originate from China. As of 2005, some 18 million total containers make over 200 million trips per year. There are ships that can carry over 14,500 twenty-foot equivalent units (TEU), for example the "Emma Mærsk", 396 m long, launched August 2006. It has even been predicted that, at some point, container ships will be constrained in size only by the depth of the Straits of Malacca—one of the world's busiest shipping lanes—linking the Indian Ocean to the Pacific Ocean. This so-called Malaccamax size constrains a ship to dimensions of 470 m in length and 60 m wide (1542 feet by 197 feet) (Levinson, 2006). Today over 60% of the world's deep-sea general cargo is transported in containers, whereas some routes, especially between economically strong and stable countries, are containerized up to 100% (Muller, 1995; Hulten, 1997).

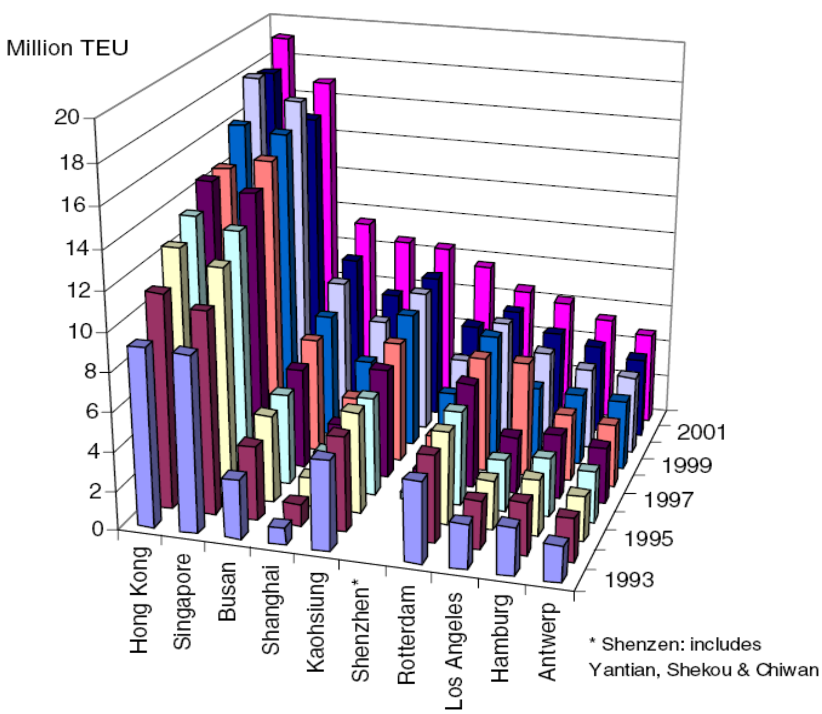

Figure 1-1 Container turnover of the ten largest seaport terminals in the world from 1993 to 2002 (ranking 2002)

By 2010, it is expected that 90 percent of all liner freight will be shipped in containers (Ioannou et al., 2000). The growth rate of container flows from now to 2020 is still expected to be 7.5% per year (Gerrits, 2007). Every major port is expected to double and possibly triple its cargo by 2020 (Liu et al., 2002). At the same time, existing and newly planned terminals are trying to attract as much volume as they can handle, which classifies the container handling sector as very competitive (Saanen, 2004).

1.1.2 Increase in the competition among container terminal operators

The increasing number of container shipments causes higher demands on seaport container terminals, container logistics, and management, as well as on technical equipment. An increased competition between seaports, especially between geographically close ones, is a result of this development. Lots of success factors of winning the competition among container seaports were identified, which are the less transshipment time and low rates for loading and discharging (see Muller, 1995; Hulten, 1997). “Therefore, a crucial competitive advantage is the rapid turnover of the containers, which corresponds to a reduction of the time in port of the container ships, and of the costs of the transshipment process itself. That is, as a rule of thumb one may refer to the minimization of the time a ship is at the berth as an overall objective with respect to terminal operations (Steenken et al., 2004).”

1.1.3 Increase in the demand for automation

Due to the enormous growth of volume and due to price declines in maritime shipping, the demand for automation of container terminals as an alternative for human-based mode of operation become more and more exigent. It is found by Saanen (2004) that an automated terminal has a relative cost advantage compared to a human-based terminal. He also argues that “although the investment cost of a robotized terminal are much higher, the overall costs can be significantly lower for such a terminal, especially when labor costs keep rising, the need for automation of control and equipment increases.”

In the research conducted by Saanen (2004), he found that many container terminal extension and new building projects were under development. The majority of those terminals will replace part of their equipment and redesign the terminal. Apart from that, a number of terminals are developing new sites into automated terminals, starting from scratch.

1.2 Introduction of APM Terminals

APM Terminals (APMT), a recognized world leader in container terminal operations and management, offers the international shipping industry the world's only true Global Terminal Network of more than 50 facilities in 31 countries and five continents (APMT' website). The current strategy of APMT is to grow strongly in the next ten years. The number of container terminals will be extended from 40(2008) to over 160 (2020). Currently, most of the APMT's container terminals are operated with manually controlled or partially automated equipment. That leads to high labor costs, especially in the European and American regions. Could automation be the optimal solution to reduce labor costs and other operational costs? This is the question which will be answered within this research.

Within APMT, the decision of designing a new terminal is proposed by the Business Development (BDV) staff and approved by the executive board. The decision making procedure for the new design is described in Figure 1-2. BDV people are responsible for researching, analyzing, identifying and negotiating future container terminal opportunities across the globe. During the way of making a business case to the board, they need to cooperate with the people in the technical department, the operational department and civil experts.

New business proposals are originating from the business development staff in the head office. Along with their proposal, they define the new business opportunity and provide the estimation of volume, cargo splits, dwell time, TEU factor, percentage of import-export and transshipment containers and terminal area. Volume is defined as the total annual moves over the quay. Cargo splits indicate the percentage of the dry, reefer and empty containers. A reefer container is a type of container typically used to store perishable commodities which require temperature-controlled storage, mostly fruits, meat, fish, vegetables, dairy products and other foodstuffs. Electricity supply is needed for reefer containers. Dwell time is defined as the period during which a container remains stored in the terminal. Based on the information provided by BDV people and additional information provided by technical staff, mode of operation, number of each type of equipment and terminal capacity will be decided upon in the operations department.

Mode of operation (often abbreviated to MOO) indicates what kind of equipment or vehicles will be used in the terminal's operation. In the meantime, BDV people will also consult experts in civil and technical fields about the technical feasibility of a new type of equipment before it will be implemented. According to the information gathered from the operations department and other relevant experts, BDV people will study the profitability of the proposed business by making financial calculations, such as NPV, IRR and payback period. Finally, the business proposal will be submitted to the executive board for discussion (see Figure 1-3).

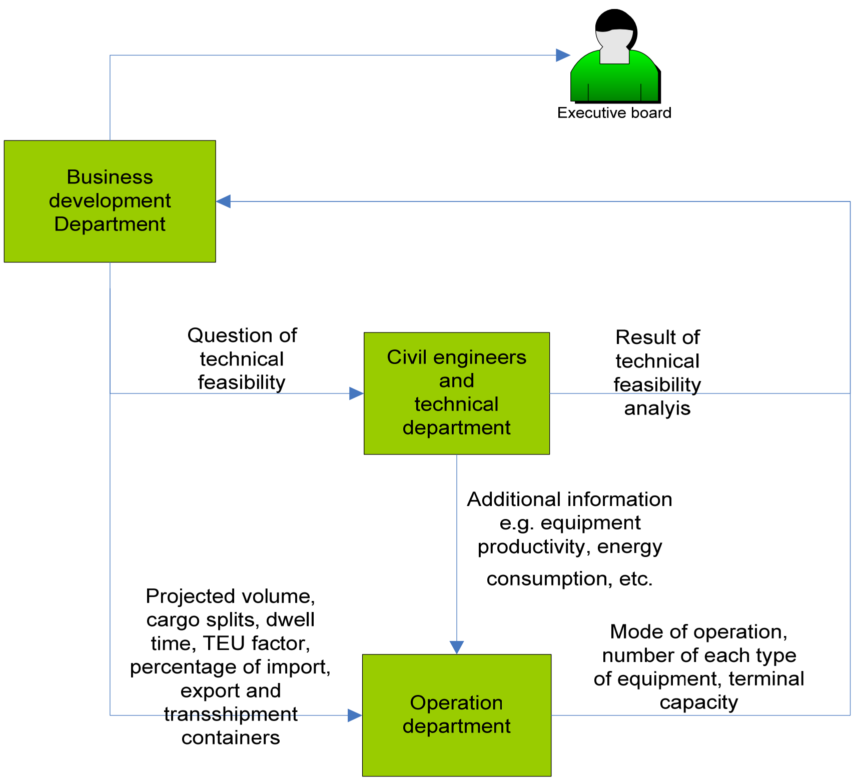

Figure 1-2 Workflows for new business within APMT

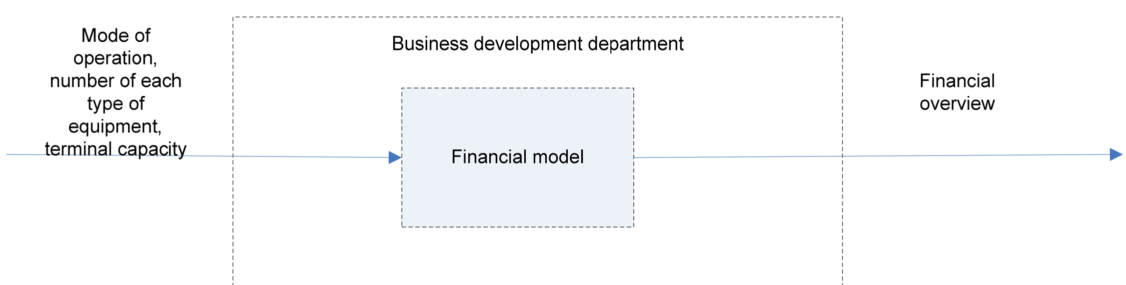

Figure 1-3 Financial model used in business development department

Within the work flow for designing a new terminal, the most important decisions being made are the choice of the MOO, the amount of equipment and the terminal's capacity. Those decisions are made in the operations department by using an Operational Model (often abbreviated to OPS) and a Business Model (BM), which are created in the operations department in the headquarter. Figure 1-4 shows how the two models are used. First, the choice of a MOO is made by the BM in terms of minimizing cost. Then, the OPS model will be used to calculate the KPIs for the entire terminal based on the chosen MOO. The calculation results will be transferred to the BDV people.

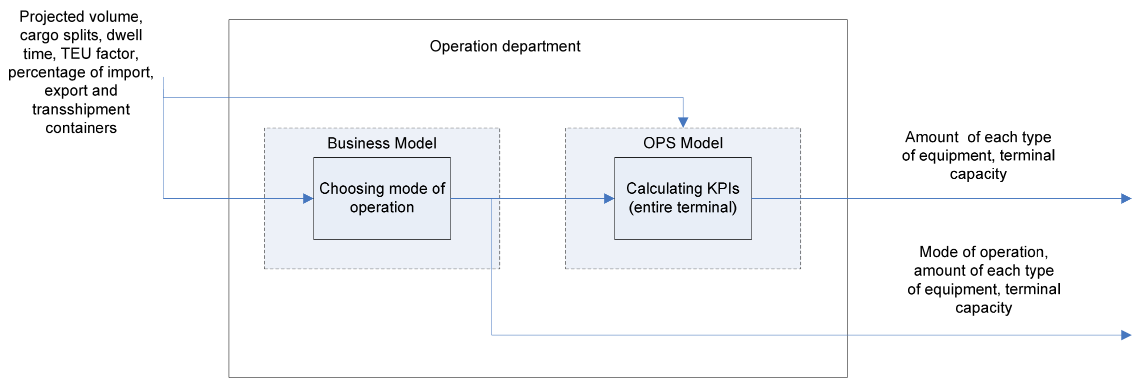

Figure 1-4 Links between BM and OPS model

Previously, only the OPS model was available for helping make the above mentioned decision. However, the OPS model is not capable of calculating KPIs for the automated equipment such as automated guided vehicles (AGVs), Rail-mounted gantry cranes (RMG) and Shuttle Carriers (ShC). In most cases, operational staff would choose one favorite mode of operation from the three possible human-based solutions which are Rubber Tyred Gantry crane (RTG), Straddle carrier (SC) and Reach Stacker (RS) by experience. There are some uncertainties on the input parameters of the model, which will be propagated through the decision chain as shown in figure 1-2. Therefore, a proper tool that can help to make a reasonable choice on the MOO is highly desired.

Recently, a prototype of such a planning tool has been developed within AMPT. This tool, which is referred to as BM, is used to determine the choice of MOO by calculating the CAPEX of purchasing certain equipment along with the OPEX associated with the usage of that equipment. Although the main purpose of the BM is to choose the mode of operation, it is also capable to calculate the amount of equipment needed, the resulting terminal capacity and other Key Performance Indicators (KPIs) regarding the terminal operation, which will also be used by BDV people (see Figure 1-4). However, the existing BM provides limited functionality; more functionality like bottleneck analysis, sensitivity analysis and more accurate calculation is required. Thus, this research will focus on developing the next version of the BM.

1.3 Outline of this report

The setup of this report is as follows: In chapter 2 the problem setting of the present research is described and the thesis objective is defined, including a framework to clearly define the scope of the research. Chapter 3 describes the container terminals in great detail and covers the structure, process and handling equipment of contemporary container terminals. Chapter 4 introduces the existing Business model, and improvements on that Business Model. Chapter 5 presents and discusses the functionality of the sensitivity analysis which is implemented in the Business Model. Chapter 6 handles a case study to illustrate the use of the model in the strategic investment decision making process. The results from the model are compared with a simulation model which is made by a terminal consultancy company that is contracted with APMT. The assessment of the improvements on the Business Model will be presented in chapter 7. Finally chapter 8 presents the conclusions and recommendations of this research.

2 Study Scope

2.1 Introduction

This chapter defines the scope of the research to be carried out. First the problem is analyzed briefly and the problem definition is formulated. On the basis of this analysis, the research objective and research questions will be stated in section 2.2. In section 2.3, the research design will be described.

2.2 Problem Analysis

Terminal operators are always challenged with strategic investment decisions in the face of a strongly growing market and a volatile demand. Often these decisions concern huge investments. Because of these huge investments terminal operators try to reduce the risks. A proper planning tool may help to achieve this.

Designing a container terminal is a complicated process, and terminal designers are always suffering from shortage of information and time for conducting systematical analysis. Kulwiec (1985) argues that a container terminal can be seen as a material handling system by referring the definition "Materials handling is a system or combination of methods, facilities, labor, and equipment for moving, packaging and storing of materials to meet specific objectives." Tompkins et al. (1996) broaden the definition to the following: "Material handling means providing the right amount of the right material, in the right condition, and the right place, at the right time, in the right position, in the right sequence and for the right cost by using the right method(s)".

Rijsenbrij (1999) mentions the steps in a container terminal design process up to the start of the technical design. Based on Rijsenbrij's finding, we can conclude that the most important decision being made during the design process is the selection of a handling system (which is also called a mode of operation), which will directly affect the investment needed for the new terminal.

Based on consultations and interviews to senior employees both in the operations department and in the business development department within APMT, it is found that terminal designers really need to be supported by a tool which considers automated solutions to help them select the mode of operation. The reasons are:

- Automated operating strategies are more and more seen as promising alternatives compared to manual operations all over the world (Liu, 2002; Duinkerken, 1999; 2002; Steenken et al., 1999; Saanen and Valkengoed, 2005).
- There is still little knowledge on the costs, performance and operational aspects of automation.
- Each business case for automation is developed from scratch.

At present, a prototype of the Business Model is used as a planning tool by APMT. The Business Model was intended to provide insight of choosing the optimal mode of operation. The optimal choice of mode of operation should be made by considering lots of aspects, such as the cost, the revenue, the local regulations; environment effects, unemployment rate and even the decision makers' preference. However, it was decided that the Business model will mainly focus on the NPV of the total cost, which consists of the CAPEX and the OPEX. Hereafter, the mode of operation which requires the least total cost will be referred as the optimal one in this research. The tool was just officially released with the first version, in which the functionality is not complete and some corrections, improvements and further validation are needed. Those incomplete and underdeveloped parts undermine the reliability of the results from the model, and may even lead the user to misleading conclusions.

Research objective

Therefore, the research objective can be identified as follow: "Improve the BM for choosing the optimal MOO, by adding new calculations and extending its functionality."

In order to better support the decision making process of choosing a MOO, both the accuracy and the usability of the BM should be improved compared to the current version. To this end, reengineering will be applied, which is described by Chikofsky and Cross (1990), as "the examination and alteration of a system to reconstitute it in a new form". Less formally, reengineering is the modification of a software system that takes place after it has been reverse engineered, generally to add new functionality, or to correct errors.

Accuracy:

In the fields of science, engineering, industry and statistics, accuracy is usually defined as the degree of conformity of a measured or calculated quantity to its actual (true) value (Schlundt, 1988**;** Miller, 1996; Hofer, 2005). In the Business Model, the calculation is partially based on input parameters such as the estimation of volume, labor cost, and equipment price and so on. The values of those parameters are decided either by analyzing the market or by previous experience, both of which have uncertainties. The accuracy of the resulting BM is therefore partially relying on the quality of the input parameters, which is out of the scope of this research. However, the reasoning process of the BM is independent of the input parameters, and it is independent of the quality of the input data. That will therefore be the focus of this research.

Usability:

Usability refers to methods for improving ease-of-use during the design process (Nielsen, 1994; Shneiderman, 1980). The definitions of usability which have been used derive from a number of views of what usability is. Three of the views relate to how usability should be measured (Bevan et al., 1991):

- The user-oriented view, that usability can be measured in terms of the mental effort and attitude of the user;

- The user performance view, that usability can be measured by examining how the user interacts with the product, with particular emphasis on either

  - ease-of-use: how easy the product is to use, or

  - acceptability: whether the product will be used in the real world.

Given the fact that the Business Model can work independently from the OPS model, and because there are some functional overlaps between the two models. The acceptability which affects whether or not the model will be used and the user satisfaction will be the main concern in this research.

Research question

The research question can be formulated as follows:

What improvements can be made to the existing business model in terms of increasing its usability and accuracy for APMT?

Here, the improvement of accuracy is not aiming at the absolute value of its result, but at the reasoning process used for getting it. The improvement of the usability will focus on adding new functionality required by the users and on improving the user interface.

In order to answer this research question, the following sub-questions should be addressed. Answering each of these sub-questions brings us a step closer to answering the main question.

(1) How is a container terminal operated? Which modes of operation are available for container terminal operation?

The answer to this question will be helpful to understand how APMT's terminals are operated, and it will help to specify the focus of this research.

(2)What is the prototype of Business Model? How does the BM function? What kind elements/ parameters should be taken into account in the BM? What improvement can be made to its calculations?

Given that the model is intended to provide insight regarding the choice of a mode of operation, the function of the model has to be in line with the functional requirements of container terminals. Those functional requirements and operational rules have to be represented in the BM. On the other hand, the calculations are based on the parameters which are decided beforehand. What kind of parameters should be in the model and what kind of parameters should not is an essential decision for the model, and the selection of those parameters must be according to the outcomes which are required by the user and the stakeholders. The improvement of the reasoning process is an important part of the main research question.

(3) How sensitive of the total cost of each mode of operation to its input parameters?

Dealing with uncertainty is one of the challenges of many quantitative risk assessment problems (Apostolakis, 2005). As Hammit and Shiyakhter (1999) underline, it is often "the lack or scarcity of data" which prevents the analyst/decision maker from assigning a certain value to the parameters. Uncertainty in the inputs is reflected in uncertainty in model's results and predictions (Apostolakis, 2005). Saltelli (2002) defines sensitivity analysis (SA) as the study of how "uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input." The uncertainty and sensitivity analysis of model predictions is important in all areas of modeling and specific modeling topics by Cooke (2006). Provided that the data used in the current business model is gathered from a limited number of regional offices within APMT, and only one definite number is used for each input parameter in the existing business model. Thus, sensitivity analysis functionality is required to address the risk of choosing a particular mode of operation.

(4) What level of blue-collar labor costs could justify a specific Mode of Operation?

It was found (Dobner et al., 2001) that the average share of labor cost as container terminals in the Hamburg-Le Havre range varies between 48% and 52% of the total operating cost. And recent data from the west coast of the United States show that the share of labor cost is even significantly higher. Therefore, labor cost can be seen as the most significant component of the operational cost. On the other hand, there is consensus in APMT that the total cost of each mode of operation is the main criterion for comparison. The main purpose of the business model is therefore to find a trade-off between capital cost and operational cost. Although the difference in white collar labor cost among the modes of operation is not obvious, the blue-collar cost for using manually controlled equipment could be much higher than when using automated equipments. Thus, labor costs for blue collar workers should be an indicator of determining the MOO.

(5) Are the usability and accuracy of the Business Model improved, and to what extent are they improved?

The answer to this question will decide if the research achieves the objective which aims to better support users to make a choice of a MOO. In this research I will mainly judge if the usability and accuracy of the BM in the experts' viewpoint.

2.3 Research design

2.3.1 Research boundaries

The research is intended to reengineer the existing Business Model to better support terminal designers in selecting a cost-effective way of operating a new marine container terminal. The modeling boundaries and the aims of the new model should stay the same. The accuracy of the comparison we aim to improve but not the accuracy of the absolute result calculated in the Business Model, because the absolute result is anyhow affected by the quality of input data. The same data collected as input parameters for the existing model will still be used during the reengineering process. The focus of this research will be on the improvement of the reasoning process and on adding new functionality based on the user's interests.

It is clear that in selecting a MOO for marine container terminals, the BM is mainly based on a comparison of the cost. The reengineering process will still comply with this rule. The consideration of legal elements, geographical and environmental conditions is outside of the scope this research.

2.3.2 Research strategy

A research strategy consists of the steps that that have to be carried out to execute an inquiry into the phenomenon studied, and it should consist of an outline of the sequence of data acquisition and analysis required to do the research at hand (de Vreede, 1995). The choice of a research strategy is based on the nature of research problem and on the status of theory development in the research field. Sol (1982) developed his inductive-hypothetic research strategy based on the Singerian inquiring system. This research strategy has been successfully used in a number research projects related to the design of support environments (see Vesteegt, 2004; Wang, 2006) and the design of logistic systems (Babeliowsky, 1997; Janssen, 2001; Streng, 1993). The inductive-hypothetic research strategy is used for the following reasons (Sol, 1982):

- It emphasizes the activities of conceptualization and problem specification, underlining specification and testing of premises in an inductive way.
- It opens up possibilities for multidisciplinary research.
- It enables the generation of various solutions, starting if possible with an analysis of the existing situation.
- It permits feedback and learning and enables evaluation of ideas.
- It is very useful when there is a lack of usable theory or methodological support.

It was appropriate to use an “inductive-hypothetic” strategy for this research. First of all, developing a business model for a container terminal requires multidisciplinary knowledge of economical, logistic and organizational aspects. Second, developing the Business Model is driven by a search for various solutions which can be implemented in a real terminal design. Third, it is a design project, and there are design cycles, adapting the design to feedback. Finally, there are some theories describing how to model logistic system and cost analysis, but they hardly refer to choosing the mode of operation in marine container terminals.

An inductive-hypothetic research strategy consists of five steps (Churchman, 1971; Sol, 1982), see also Figure 2-1:

1. Initiation: using a number of rudimentary theories some empirical situations are described.
2. Abstraction: the essential aspects are abstracted into a conceptual model.
3. Theory formulation: using the descriptive model a prescriptive conceptual model is derived in the form of a theory.
4. Implementation: test the theory the model is implemented in one or more prescriptive empirical situations.

5. Evaluation: the results of the prescriptive empirical situations are evaluated.

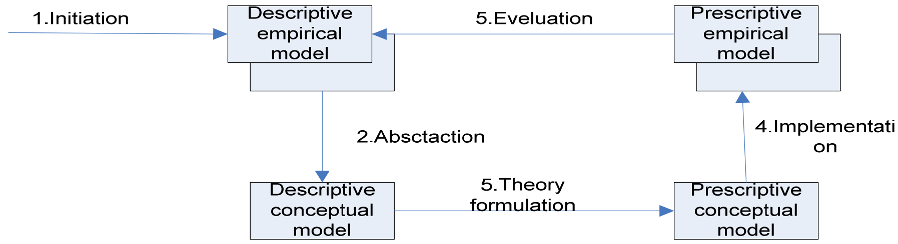

Figure 2-1 Inductive- hypothetic research strategy

Before this research starts, there is already a prototype of the Business Model, which is seen as a prescriptive empirical model. The model will used as a descriptive model to abstract knowledge on container terminal operation. The adaption of Figure 2-1 is made in Figure 2-2.

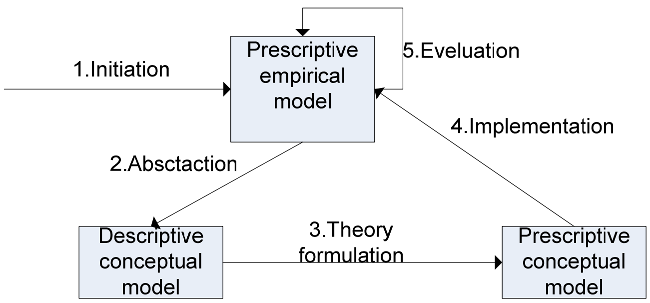

Figure 2-2 Adaption of Inductive- hypothetic research strategy

2.3.3 Research instruments

Research instruments are used to describe the way the data is collected and analyzed (Janssen, 2001). Various research instruments are available, such as experimenting, action research, survey, desk research, case study and interview. Research instruments should also be in line with the research objectives. Provided that the research opts for understanding container terminal operation and testing the sensitivity of the calculated result subject to the given inputs and the reliability of the models' outcomes, literature review, experiment case study and interviews are the most appropriate in this research.

Literature review: A review of journals, periodicals, and other research publications related to the subject area was executed during the initial phase of the research and updated throughout the research. The main purpose was to obtain a comprehensive understanding of what has been done in the domain of container terminal operation domain.

Experiment: An experiment is the most suitable type of research for gaining experience with newly created situations or processes, which can be used to assess the effects of these changes. For the sensitivity analysis, experiments will be conducted to test the model's outcomes along with the changes of input parameters.

Case study: Case studies as research instruments have been successfully used in a number research projects that follow the inductive-hypothetic research strategy (de Vreede, 1995; van Laere, 2003; Sol, 1982, Vesteegt, 2004; Wang, 2007). Yin (1989) defines the case study as empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomena are used and when multiple sources of evidence are used. Case studies also give the investigator the chance to apply a multi- method approach to a topic. Yin also addressed that case studies are the preferred strategy for studies dealing with the "how" or the "why" question. Provided that employing automated equipment is taken into consideration when designing the Business Model, validation of the model by comparing the outcome with reality is going to be an impossible mission, unless there are already lots of automated container terminals existing all over the world whose data are available. However, case studies allow us to judge the validity of the model by comparing it to the results from other sources.

Interviews: To address the question regarding the usability, interviews are seen as the most appropriate way. It is expected to gain knowledge if the experts feel the accuracy of the Business Model improved, and whether the new functionality is useful.

3 Description of container terminal operation

3.1 Introduction

Over the last four decades the container as an essential part of a unit load-concept has achieved undoubted importance in international sea freight transportation. With ever increasing containerization the number of seaport container terminals and competition among them has become quite remarkable. In this chapter we introduce the container terminal system while emphasizing on the handling equipment and the container terminal process, which are the major elements in the Business Model. It will end with the description of KPIs related to container handling systems which will be calculated in the Business Model.

3.2 Structure of container terminal

A container terminal is a facility where cargo containers are transshipped between different transport vehicles, for onward transportation. The transshipment may be between ships and land vehicles, for example trains or trucks, in which case the terminal is described as a maritime container terminal. Figure 3-1 shows a bird' eye view of the Maasvlakte, where APMT's terminal is located within the red circle. In general, container terminals are consider as material handling systems which have two interfaces, for input and for output flows. The interfaces are the waterside with loading and unloading of ships, and the landside where container are loaded and uploaded to trucks and trains. In the heart of the container terminal is a stacking area, where containers are stored temporarily. The marine apron a space designed for vehicles' traveling, which is located between the stacking area and the berth quay (see Figure 3-1).

Figure 3-1 Bird' eye view of port of Maasvlakte (source: google earth)

3.3 Function and process of a container terminal

3.3.1 Function of a container terminal

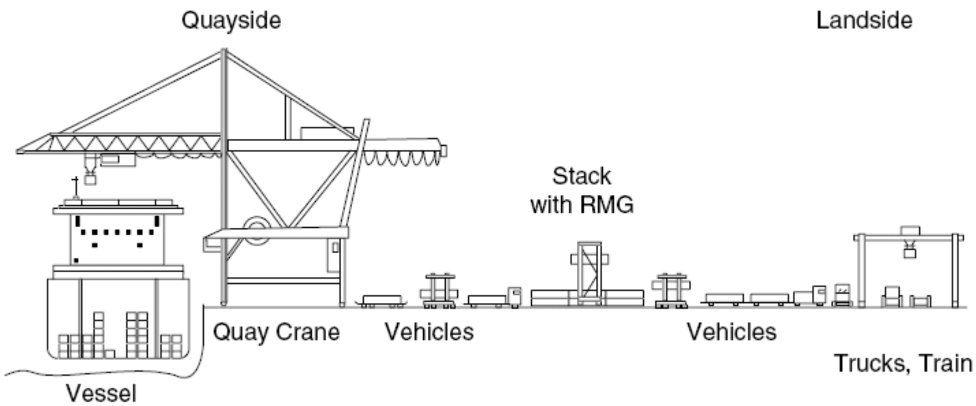

Figure 3-2 Cross-sectional view of terminal operation (Steenken et al., 2004)

Usually, a container terminal has two major functions, which are transshipment and storage. Transshipment is quite obvious, which includes the transportation of container from one mode to another mode (See Figure 3-2). Storage as an import functionality of container terminal is sometimes being underestimated. It is proposed to put more attention on the storage function by (Saanen, 2004). The reasons are argued by (Van zijderveld, 1995):

(1) Direct transshipment would make the processes at the terminal too complex; in case of transshipment from a marine vessel onto road trucks this would result in complex controlling of all individual road trucks, to make sure that they arrive in the right order to fetch their container.
(2) Direct transshipment would yield a complex terminal design for those terminals that include more than two modes of transport: all modes of transport that are handled should come very close to each other, which immediately causes difficulties for terminals that includes barges, marine vessels, road trucks and trains.
(3) Direct transshipment would require the simultaneous presence of both means of transport between which load units are transshipped. Especially direct transshipment of load units between marine vessels and trains is virtually impossible due to the great diversity of destinations of load units, the strict loading sequences of trains and vessels, and the great length of trains.

3.3.2 Processes at container terminals

The processes for a container terminal are specified as follows (see

Figure 3-3):

(1) Loading and uploading over the quay
(2) Waterside transport: deliver containers to the stack
(3) Handling of containers to the stack
(4) Yard handling
(5) Handling of containers to another transportation mode (truck, train, barge)
(6) Landside transport: deliver containers to gate and train

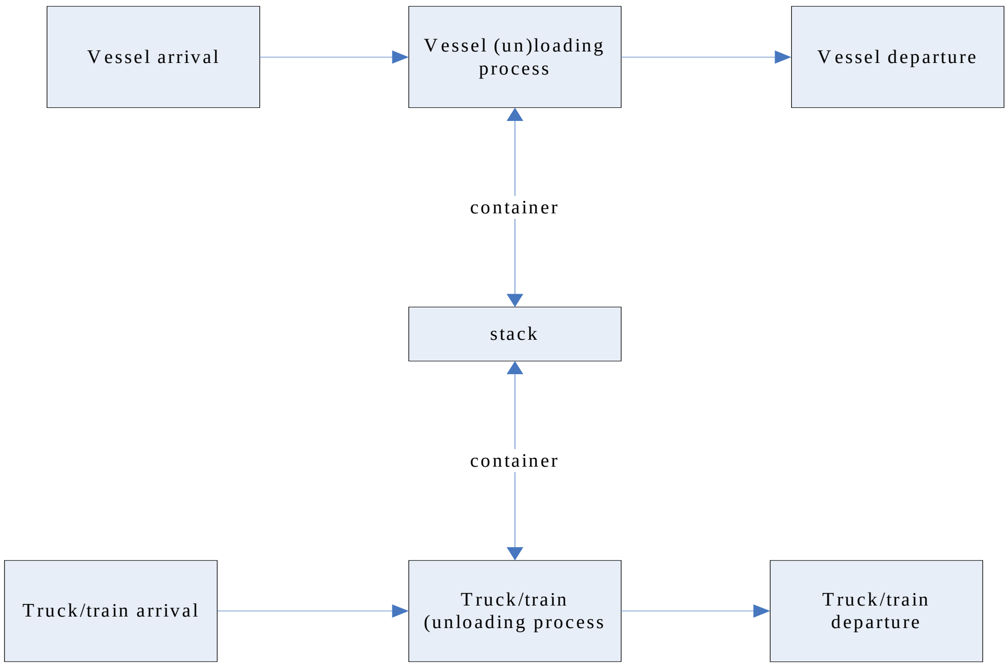

Figure 3-3 Schematic picture of a container terminal process (Saanen, 2004)

3.4 Handling and horizontal transport equipment

In reality, container terminals are characterized particularly with respect to the handling equipment and transporting vehicles. From the logistic point of view, there are only two types of equipment: stacking and transporting. In literature these are sometimes referred as Vertical transportation and Horizontal transportation (Steenken et al., 2004). In the rest part of this chapter, I will elaborate on describing the two types of equipment which are widely used in contemporary terminals.

3.4.1 Vertical transport means

① Loading and loading containers over the quay

Although different types of equipment are employed for handling the transshipment tasks, the major equipment is Quay Crane, which loads and unloads vessels. There are two common types of container handling gantry crane: high profile where the boom is hinged at the waterside of the crane structure and lifted up in the air to clear the ships for navigation; the second type is the low profile (goose neck) type where the boom is shuttled/pulled towards and over the ship to allow the trolley to load and discharge containers. Low profile cranes are used where they may be in the flight path of aircraft such as where a container terminal is located close to an airport. The high profile cranes are the taller of these which are shown in the Figure 3-4. Quay cranes are located along the berth, with required minimum meters of distance. The maximum performance of quay cranes depends on the crane type. The technical performance of cranes is in the range of 50–60 containers/h, while in operation the performance is in the range of 22–30 containers/h. Berth capacity is determined by the performance of the quay cranes, which equals to the maximum productivity of all the quay cranes together. As Saanen (2004) argues, the trend towards larger vessels has to be followed by larger cranes and faster cranes, hence if all other things are equal, the cycle time of the cranes increases.

Figure 3-4 Side-view of the Super-PostPanamax gantry cranes at APM Terminal in Port of Rotterdam (source: APMT)

② Yard handling

To place a container into the stack and retrieve it from the stack, we need another category of vertical handling equipment in stack area. At present there are two types of crane used in the terminals owned by APMT, which are rubber tired gantries (RTG) and rail mounted gantry cranes (RMG), see Figure 3-5.

a b

Figure 3-5 RTG (a) and RMG (b) used in APMT's terminal, Virginia (Source: APMT)

An improtant difference between rubber tired gantries and rail mounted gantry cranes is the following: RTGs are quite difficult to automate while RMGs are fully automated. "It is difficult to improve the positioning accuracy of RTG's, because they are moving on wheels, and therefore automating them is more costly" said by APMT professionals. Often, in terminal operation two RMG cranes are employed in one stack module (block), where one crane can serve at the waterside, while the other one can serve the landside at the same time. This has proved to be a productive and reliable way of operation under the consideration of that one can be used as a back-up in case the technical failure happens to the other one (Steenken et al., 2004).

3.4.2 Horizontal transport means

Several types of internal transport equipment are employed in current terminals. That includes: ① Straddle Carrier (SC), Reach Stacker (RS), Shuttle Carrier (ShC) ② Automated Guided Vehicle (AGV), Terminal Tracker (TT).

a b

Figure 3-6 Pictures of RS (a) and SC (b) (Source: APMT)

Those equipments listed in group are manually controlled, even though some trials are conducted with automated Shuttle Carriers and Straddle carriers in Patrick Terminal/Brisbane, Australia. Furthermore, those equipments not only transport containers, but are also able to stack containers in the yard. Therefore, they can be regarded as ‘cranes’ that are not locally bound, with free access to containers independent of their position in the yard. Straddle carriers (SC) are the most important and widely used ones of it (See Figure 3-6 a). Reach Stackers (RS) (See Figure 3-6 b) are not an interesting option any more, which is because “RSs are not seen as an advanced technology which is advocated in EU; RS have relatively low efficiency which can not handle the required huge throughput in marine container terminals; RS require more space in the stacking area that makes it not attractive” according to APMT professionals. The straddle carriers’ spreader allows transporting either 20’ or 40’ containers; twin mode to transport/stack two 20’ containers simultaneously is becoming available. Because of their properties, straddle carrier systems are very flexible and dynamic. Straddle carriers exist in numerous variants. Usually straddle carriers are man-driven and able to stack 3 or 4 containers high, i.e., they are able to move one container over 2 or 3 other containers, respectively. These are capable of relatively low speeds (up to 30 km/h) with a laden container.

The second group of equipment can only transport containers from quay side to the stack area or from stack area to the rail. Loading and unloading of these vehicles is done by cranes, either quay cranes or stacking cranes. AGVs are the most important means in most of the automated container terminals. They are robotized to drive on a road network which consists of electric wires or transponders in the ground to control the position of the AGVs. AGVs can either load one 40’/45’ container or two 20’ containers. As AGV systems demand for high investment, they are only operated where labor costs are high; they are now in operation at ECT/Rotterdam and at the HHLA/Hamburg – in combination with automatic handling cranes.

The various types of operating equipment that have been described are often employed together, e.g. in the port of Gothenburg, Sweden, SCs are used for the horizontal transfer of containers, while RTGs are employed in loading and unloading containers from rail wagons. The choice of a container terminal’s mode of operation has an influence on the performance of a terminal as well as on the amount of land space required. In Table 3.1, a brief comparison, based on work by De Monie (2005) of the four main types of operating equipment is presented.

Within this research, only the following combinations are taken into account: SC, RTG/TT, RMG/AGV, RMG/ShC, which are either currently used or look promising for future implementation for APMT.

Table 3.1 Examples of CT operating systems and land used per annum

Operating Equipments	**m^2 per 1000 TEU p.a.**	**Examples of operating system employed**
SC	20000	Norfolk, Antwerp, Zeebrugge, Gothenburg
RTG	12000	Antwerp, Rotterdam
RMG	8000	Kaoshiung
AGV/ASC	2500	ECT in the Netherlands (with automated stacking cranes, ASC)

3.5 KPIs for container terminal handling system

In order to evaluate the functionality and service a terminal provides, Key Performance Indicators (KPIs) have to be defined, which are linked to the objectives of a terminal (Saanen, 2004). In addition to providing a suggestion for choosing the optimal mode of operation, the Business Model should also be helpful to judge a terminal’s performance.

Some important KPIs of a terminal which should be taken into account in the Business Model are the following:

① Productivity of Quay Crane (moves/ crane hour)

The productivity of a Quay Crane is defined as the number of containers handled by the crane per hour during a berth operation. This is one of the most important indicators for analysis and evaluation of the productivity of existing container terminals, as well as for planning of new container terminals, because quay cranes are expensive and the quayside determines a significant percentage of the total terminal costs (Saanen, 2004).

② Productivity of other container handling equipment (moves /equipment hour)

This is another important indicator for both evaluating existing terminals and designing new terminals. The productivity of handling equipment is affected by other factors, e.g. performance of transport vehicles, operator skills, operation strategies et cetera. Basically, four kinds of productivity can be identified, which are technical productivity, operational productivity, net productivity and gross productivity. Technical productivity is the theoretical maximum productivity of the handling equipment. It is determined by physical factors. Operational productivity is determined by the operational condition which includes the influence of the wind, the surface condition et cetera. Net productivity is calculated the number of productive moves divided by the production time. Interactions with other equipment are taken into account in the calculation of net productivity. Gross productivity is the most important indicator during the terminal planning. It includes all the disturbances which exist in the previous three types of productivities. Thus, gross productivity is the indicator should be used in the practice of handling system planning.

③ Annual container handling capability per area unit (TEU / hactare)

Base on the annual container handling capability it is a convenient index for planning, analyzing or benchmarking container terminals (Saanen, 2004).

④ Annual container handling capability per meter quay (TEU / m)

The quay wall is one of the main cost factors of a terminal. The throughput in relation to the quay wall length is an indicator to check the terminal’s efficiency. The annual container handling capability per total length of quay wall varies between 150 to 2000 TEU per m / year (Saanen, 2004).

⑤ Cost per move

A major issue concerning the design of container terminals is the cost. Cost per move includes all the expenses made on the terminal. It is an important indicator when making the pricing policy and judging the cost efficiency for a terminal.

⑥ TEU per headcount

The labor cost is most interesting when looking at automated terminals, since the largest saving comes from the reduction of the workforce (Drewry, 1998; Dobner, 2002; Saanen, 2004). However, the labor costs vary considerably from port to port and from country to country, and therefore it is difficult to generally benchmark terminal performance by capacity per labor costs. Alternatively, TEU per headcount is a fair indicator that is because of the labor' efficiency is not varying a lot.

By comparing the above mentioned KPIs with those that have been benchmarked in the industry or APMT, a terminal planner can judge whether a solution for a terminal is operationally and economically feasible.

This chapter reviewed a container terminal's structure, process and functions on which the Business Model is based. Various types of equipment were also presented in this chapter. Those different types of equipment are the objects which were considered by and compared in the Business Model. Besides, several key performance indicators described here need to be calculated and presented in the Business Model.

4 A Business Model for a marine container terminal

4.1 Introduction

A review of the existing Business Model is presented in section 4.2, which includes the background, model boundary and the input and output of the Business Model. In section 4.3, the requirements for improvement of the model will be described, that is on the basis of stakeholder analysis and requirements analysis. An approach of improving the model will be presented in section 4.4. Finally, the improvements over the old model are described in section 4.5.

4.2 Review of the existing Business Model

4.2.1 Background for the Business Model

The previous version of the Business Model was created for APMT in 2007. It was driven by the demand for a tool which could be used to choose the mode of operation for future terminals. Before the Business Model was available, an OPS model was used as a tool to calculate a terminal's operational indicators such as terminal capacity, amount of equipment and required terminal area. In the OPS model only human-based modes of operation are taken into account such as RTG, SC and RS, while the automated modes look more and more promising at present.

4.2.2 The Modeling platform

The Business Model is implemented using Microsoft Excel, because Excel has the following advantages:

- Easy and quick to start
- Transparent to both users and developers, easy to track the calculation
- Convenient for maintenance and correction
- The outcomes are easy to incorporate with the financial model which is based on excel as well.

4.2.3 Model boundaries

The Business Model includes all the elements which influence the choice of a mode of operation. Its boundaries are set in both a logistic perspective (see Figure 4-1) and in an economic perspective.

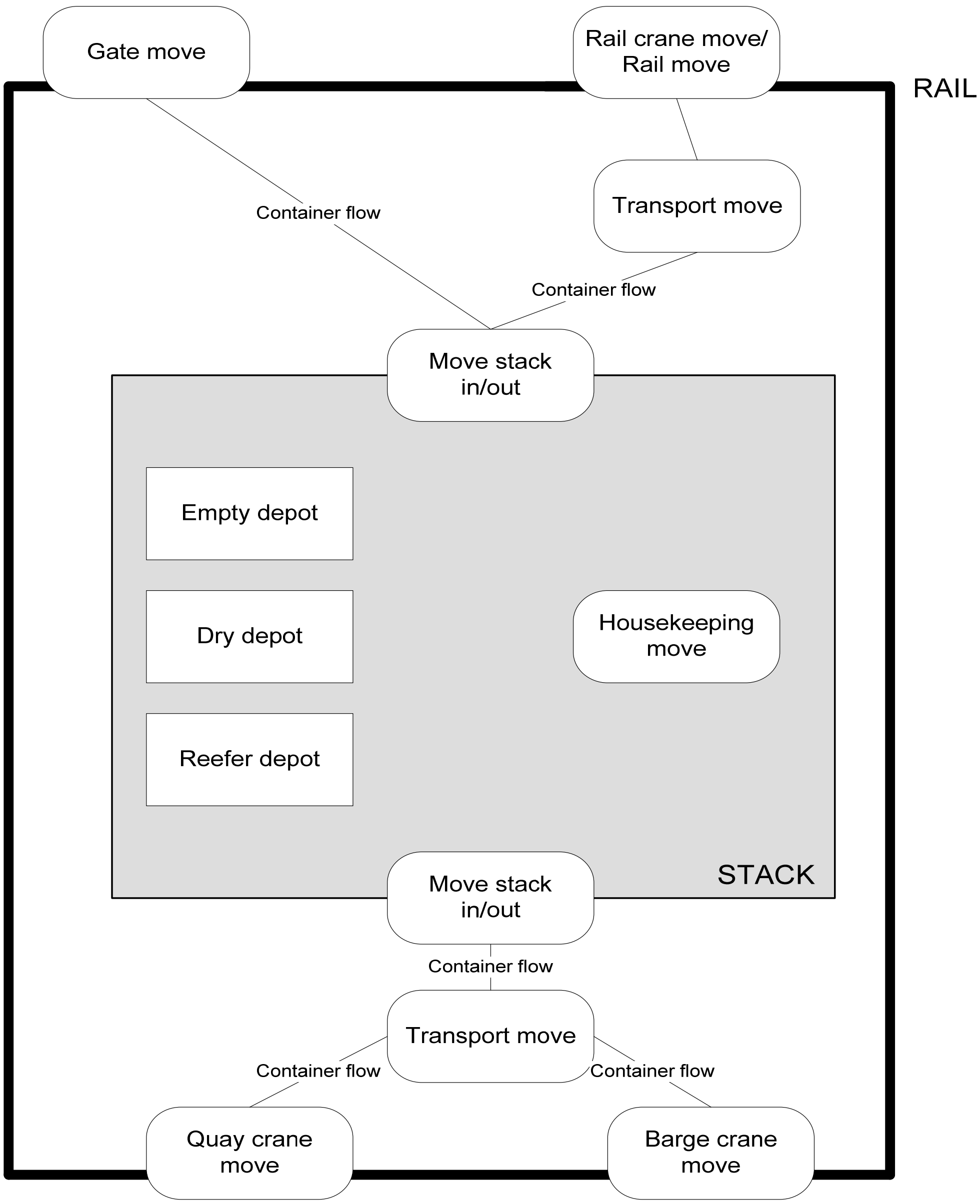

Figure 4-1 Boundaries of Business Model in logistic perspective (Source: Documentation of Business Model of APMT, 2007)

From a logistic perspective, the model’s boundary is set from a vessel’s arrival at the quay to the departure of a container by truck or by train. The process is independent on any modes of operation before the vessel’s arrival and after the container’s departure.

From the economic point of view, only the cash flow at the investment side is taken into account. This is based on the assumption that each mode of operation has to achieve the same throughput volume, as the revenue is the same regardless the mode of operation. Therefore, IRR and payback time are also not needed to consider as criteria for comparison.

4.2.4 Inputs and outputs of Business Model

The Business Model contains several input sheets, which allow user to specify the input parameters regarding projected volume, equipment specification, terminal specification and financial factors, and output sheets, in which the result is shown as numeric figures and graphics (See Figure 4-2).

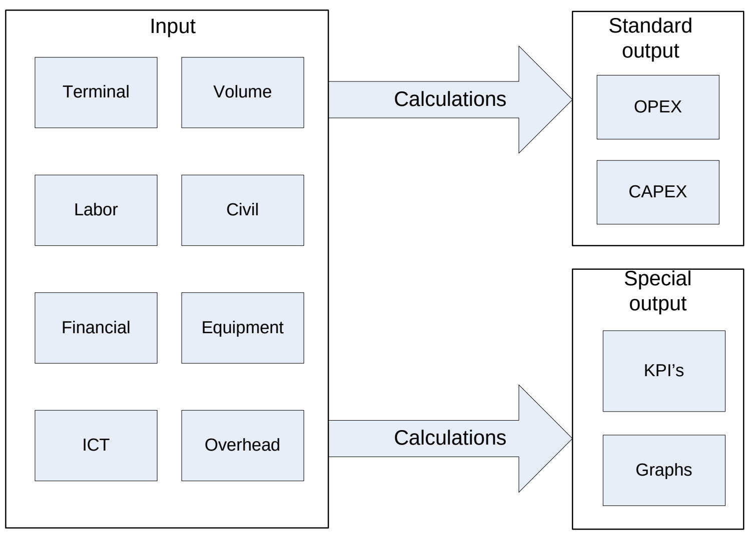

Figure 4-2 Structure of Business Model (Source: Presentation of Business Model of APMT, 2007)

The CAPEX and OPEX for each mode of operation are calculated based on financial principles (See the definition of both CAPEX and OPEX). The important input parameters for each input sheet and the relationship among input sheet and output sheet are presented in appendix I. The snapshot of the Business Model is presented in appendix II. Basically, the recommended mode of operation is the one which requires the least total investment, which consists of both CAPEX and OPEX. Normally, using automated modes of operation requires advanced technology which is associated with high CAPEX, but low OPEX because of that less manning is needed and the equipment have higher efficiency during the operation, while human-based mode of operation leads the reverse situation.

4.3 Reengineering the existing Business Model

4.3.1 The way of working

Reengineering of the Business model starts from an identification of the problems and requirements for improvement for the existing business model. Theory and results of consultation of domain experts are used to guide the implementation. Evaluation of the implementation will be done by expert interview and case study (see Figure 4-3).

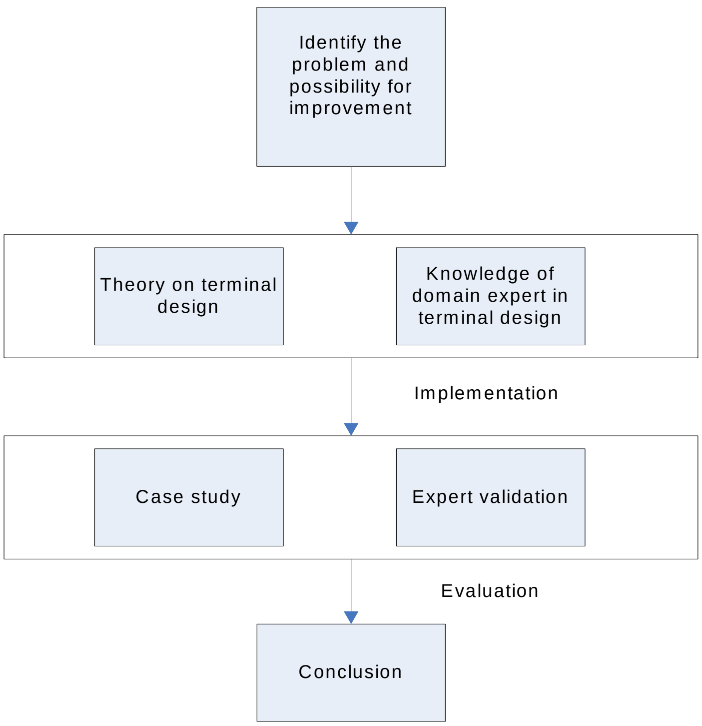

Figure 4-3 Framework of reengineering the Business Model

4.3.2 Stakeholder analysis

"A stakeholder is defined as any person or organization that can be positively or negatively impacted by, or cause an impact on the actions of a company. Stakeholder analysis is a form of analysis that aims to identify the stakeholders that are likely to be affected by the activities and outcomes of a project, and to assess how those stakeholders are likely to be impacted by the project. Stakeholder analysis has the goal of developing cooperation between the stakeholder and the project team and, ultimately, assuring successful outcomes for the project.” [2]

In the research, stakeholder analysis is necessary because of the facts as following:

- The intention of the research is providing a tool, which must be useful and its results should be acceptable by the users. Understanding the demands of the user can reduce the risk of failure of a project, and also take the model directly to the point where the user expects.
- As an important tool for the company, the way of developing and way of working of the tool should be validated or at least screened by stakeholders.

Several approaches of stakeholder analysis were learnt from literature review. Mitchell et al. (1997) proposed a classification of stakeholders based on power to influence, the legitimacy of each stakeholder’s relationship with the organization, and the urgency of the stakeholder’s claim on the organization. The results of this classification may assess the fundamental question of “which groups are stakeholders deserving or requiring manager’s attention, and which are not?” This is salience “the degrees to which managers give priority to competing stakeholder claims”. Turner and Kristoffer (2002) have developed a process of identification, assessment of awareness, support, influence leading to strategies for communication and assessing stakeholder satisfaction, and who is aware or ignorant and whether their attitude is supportive or opposing. Savage et al. (1991) offer a way to classify stakeholders according to potential for threat and potential for cooperation.

Stakeholders for the development of the Business Model and the users of the Business Model and are identified in the following two ways:

- Consultation of the developer of the previous version of the Business Model.
- Observation the use of the Business Model to make a business case,

From the consultation of the previous developer, stakeholders during the development phase of the Business Model are identified as shown in Figure 4-4.

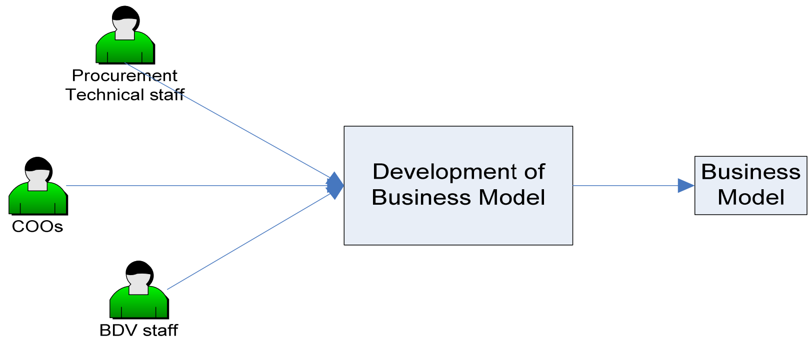

Figure 4-4 Stakeholders for the development of Business Model

The Chief Operational Officers (COOs) and Business development staff provide ideas and ask for functionalities of the Business Model, while the BDV people also provide the input data such estimation of volume, modal splits, cargo split, teu factors. At the mean time, procurement, operational and technical staffs are also supporting the development process by providing inputs for the Business Model, such as equipment price, equipment productivity, and energy consumption and so on.

The stakeholders of the Business Model has been identified by observing the process of making a business case, which is about judging the economical feasibility of using a new mode of operation in the Maasvlakte II project. The typical workflow of making a business case in APMT is described in chapter one (see Figure 1-2). It is also applied to the F-crane case. After the technical feasibility of the F-crane has been approved by the technical staff, the Maasvlakte II team judges the economical and operational feasibility by using the business model. The team consists of business development people; people who have operational experience and who support using the Business Model. Details of this case will be presented in chapter 6. In this case study, BDV people are seen as the most important user, who uses the output of Business Model to calculate financial indicators such as NPV, IRR, and payback time. Besides BDV people, there are also other stakeholders such as the regional COOs and the person who is interested in the result provided by the Business Model (see Figure 4-5).

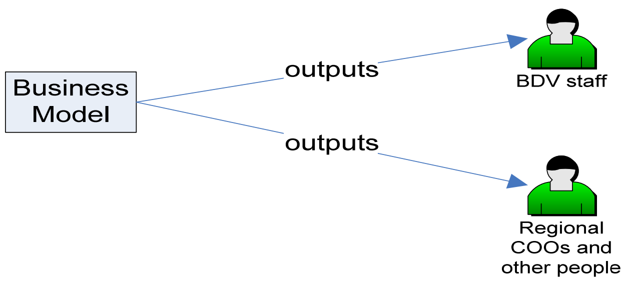

Figure 4-5 Stakeholders for the use of Business Model

4.3.3 *Requirements analysis*

Requirements analysis is critical to the success of a development project. Requirements analysis encompasses those tasks that go into determining the needs or conditions to meet for a new or altered product, taking account of the possibly conflicting requirements of the various stakeholders, such as beneficiaries or users. [3]

There are many techniques that can be used to make requirements analysis, such as : stakeholder interviews, Joint Requirements Development Sessions (JRDS) and measurable goals. Prior to the start of this research, interviews had been done with stakeholders for the development of the Business Model by the previous developer.

A Joint Requirements Development Sessions has been held during the early stage of this research. The attendees include the BDV manager and the developer of Business Model and the OPS Model. The required output from the Business model is clarified by the BDV representative.

Given the time of this research is limited, not all of the requests from the stakeholders will be fulfilled in this research. Only a few prioritized requests will be implemented. BDV people as the most important user of the Business Model, their requirements have to be prioritized. On the other hand, from the organizational point of view, the people at the high levels of the organization are seen as the critical stakeholder, since they possess the authority to judge this project. A summary of stakeholder analysis and requirements analysis are shown in Table 4.1. Those requirements will be concentrated on during this research (see section 4.4)

Table 4.1 Summary of stakeholder analysis and requirements analysis

Stakeholders	Influence to development of the BM	Required outcome from BM
BDV people	High	• Optimal choice of MOO • Number of each type equipment • CAPEX and OPEX for a given type of MOO • Terminal capacity / Bottleneck of terminal capacity
COOs and other stakeholders	High / Moderate	• Depreciation of CAPEX • Result of sensitivity analysis • Graphs showing the modal split and land used

4.4 Reengineering the existing Business Model

The implementation is based on either on the consultation of the domain expert or the theory with respect to the problem.

4.4.1 Depreciation of CAPEX

Cost per move is an important indicator for terminal manager to make the pricing policy and also for the comparison with other terminals. It is calculated based on nominal cost as shown in Figure 4-6 :

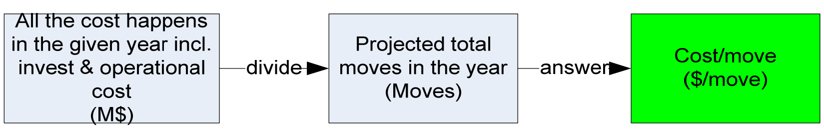

Figure 4-6 Calculation of the cost per move in a given year

The total cost in a given year consists of OPEX and CAPEX, which is not depreciated yet in the previous version of the Business Model. This means that when purchasing some new equipment which can be used for ten year for example, all the expenses on those equipments are counted only to the year when the payment happens. However, it is not suitable to calculate the value of cost per move.Figure 4-7 shows the cost per move for the SC solution in the previous Business Model.

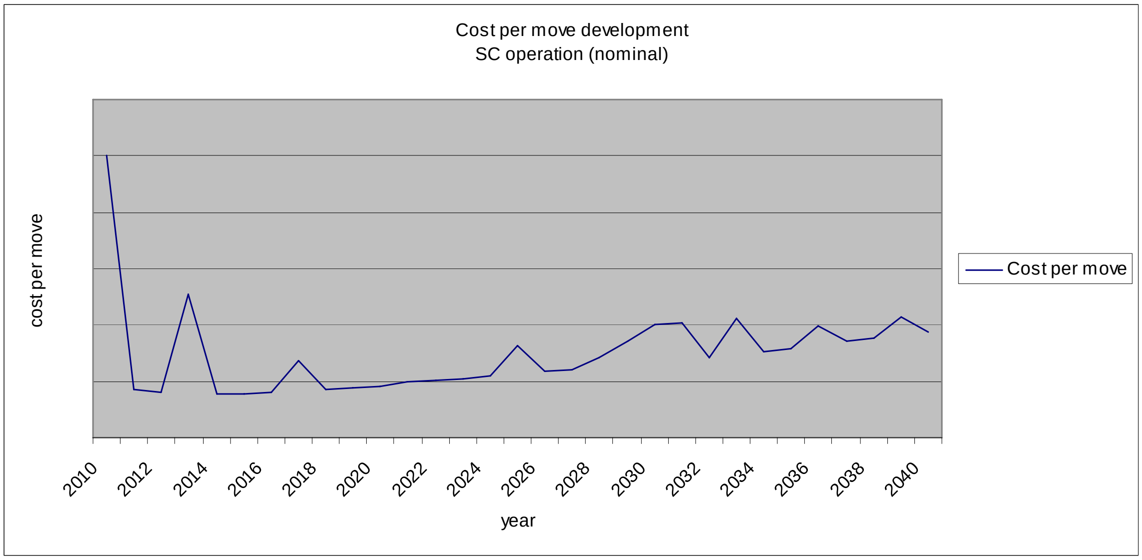

Figure 4-7 Cost per move for SC in previous BM (All the numbers here are for example only; they do not represent the actual figures)

Intensive fluctuation is observed, which is because of the total cost is significantly high when new payment happens but not in the other years. In order to solve this problem, depreciation cost should be used. By consulting professionals in APMT, it is decided to use straight-line method and set the savage cost equal to zero. That means there is neither remaining value from selling the equipment after its technical lifetime nor additional cost to remove the equipment. In the implementation, the depreciation cost is calculated through dividing investment by equipment life span (Figure 4-8); the implementation steps for adapting the spread sheet are presented in appendix III.

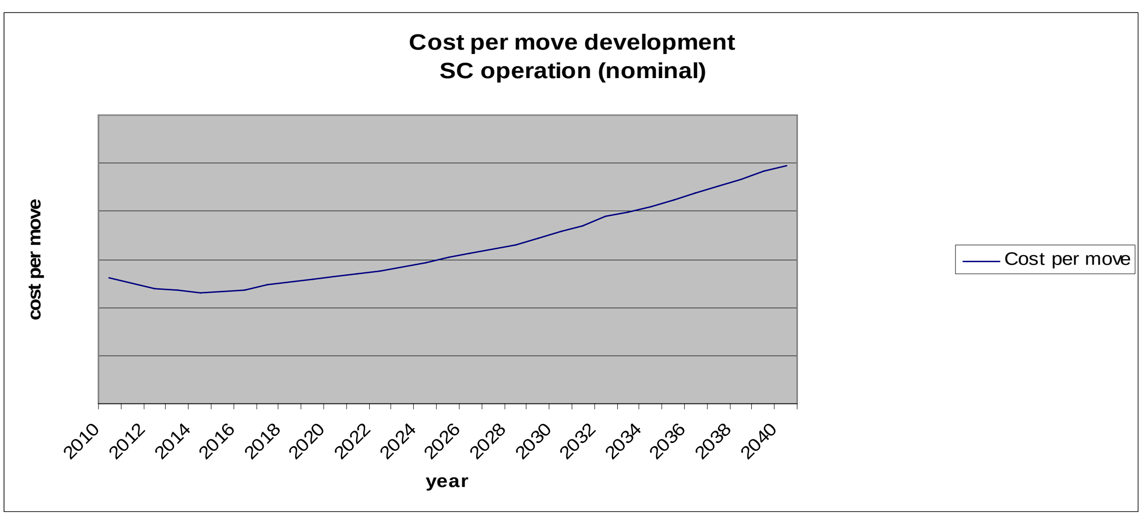

Figure 4-8 Cost per move for SC in current BM (All the numbers here are for example only; they do not represent the actual figures)

In Figure 4-8, the first fall of the curve is because of the relatively high OPEX, which is caused by the low starting productivity of equipment, and afterwards the curve is increasing smoothly, which is quite reasonable in real terminal operation.

4.4.2 Calculation for equipment utilization

In the previous Business Model, the maximum productivity of equipment is assumed to be a fixed number. The amount of equipment required is calculated by the following formula:

$$Amount\ of\ equipment = \frac{Projected\ volume}{Yearly\ operating\ hour\ per\ equipment} \tag{4.1}$$

The running hours per year is calculated by:

$$Yearly\ operating\ hour\ per\ equipment = \frac{Projected\ volume}{Equipment\ gross\ productivity * Amount\ of\ equipment} \tag{4.2}$$

The Business Model also provides a graph of equipment utilization, which contains the following elements:

- Operating time
- maintenance & repair time (M & R)
- Idle time

Operating time can be gotten from formula (4.1), and M & R time is calculated by following formula:

$$M\ \&\ R\ time = Yearly\ operating\ hour\ per\ equipment * M\ \&\ R\ factor \tag{4.3}$$

Where, M & R factor show the required M & R time per operating hour

Idle time is calculated by formula (4.4):

$$Idle\ time = Total\ terminal\ operating\ time - Yearly\ operating\ hour\ per\ equipment - M\ \&\ R\ time \tag{4.4}$$

Formula 4.5 can be gotten from transforming formula 4.4:

$$Total\ terminal\ operating\ time = Yearly\ operating\ hour\ per\ equipment + M\ \&\ R\ time + Idel\ time \tag{4.5}$$

Use formula (4.3) replaces the M & R time in formula (4.5), and then we can get formula (4.6)

$$Maximum\ yearly\ operating\ hour\ \ per\ equipment = \frac{Total\ terminal\ operating\ time}{1 + M\ \&\ R\ \ factor} \tag{4.6}$$

The amount of equipment required can be calculated by combining the formula (4.1) and formula (4.6), and the equipment utilization in new model is shown in Figure 4-9, which is approved by APMT's operational expert.

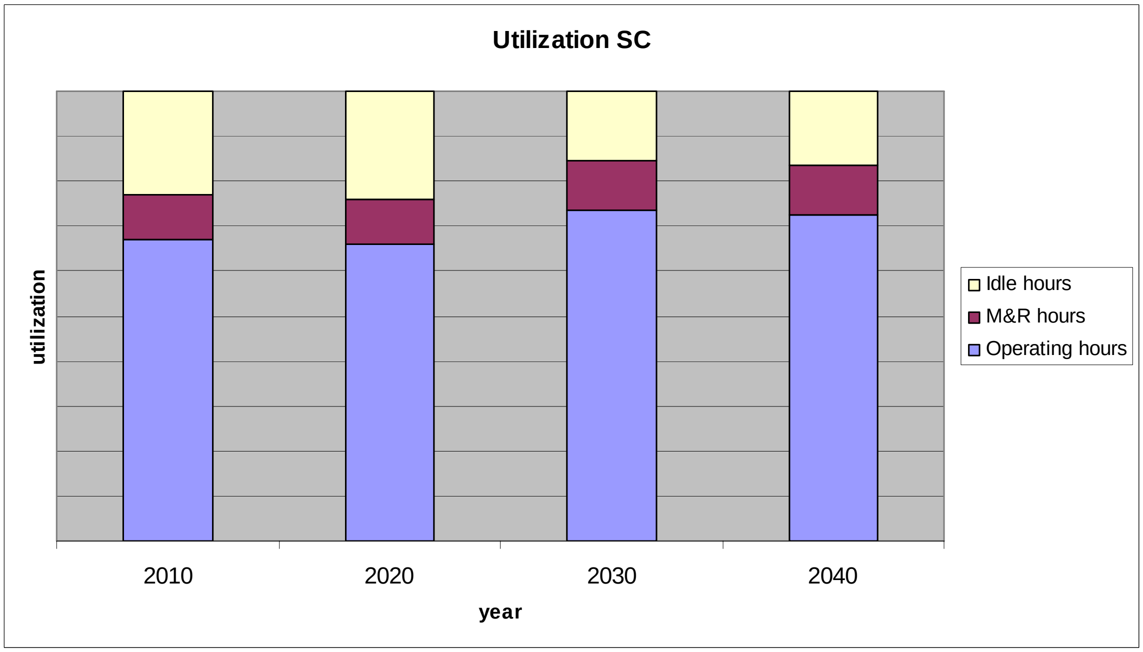

Figure 4-9 Utilization of SC in current BM (All the numbers here are for example only; they do not represent the actual figures)

4.4.3 Bottleneck analysis

Graphics showing the bottlenecks of terminal capacity are required by the BDV manager. Those graphs will help them to identify when and which part of the terminal should be expanded, when actual volume increases.

From the literature describing terminal design, the potential bottlenecks are identified among berth capacity, yard handling capacity, yard storage capacity and ground transport capacity (Saanen, 2004). The mutual dependencies of those elements are shown in Figure 4-10.

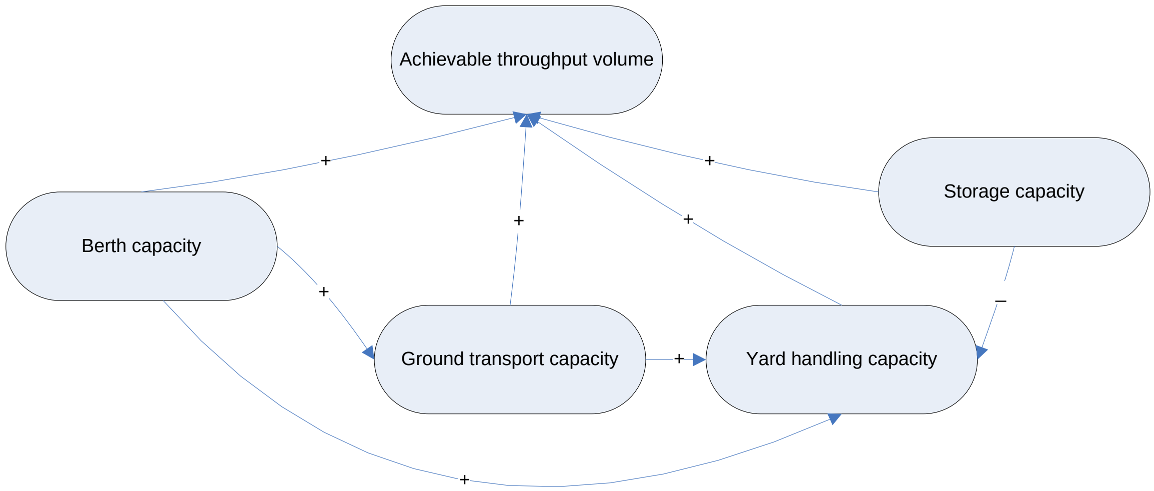

Figure 4-10 Mutual dependencies of key elements

Increasing capacity on those elements will increase the actual capacity of terminal. High berth capacity requires high ground transport capacity and yard capacity. Under the limitation of reserving enough space for stacking, yard handing capacity and yard storage capacity should be balanced.

As long as the scenario of project throughput volume is available, all kind of terminal parameter such as the required waterside handling capacity, yard handling capacity, and quay length can be determined.

Waterside handling capacity

In most cases, quay length is not a limiting factor for the water side handling capacity, while the number of quay cranes and the gross productivity are the most important determining factors. Therefore, we can conclude that the waterside handling capacity is determined by (see also Saanen, 2004):

a) The number of quay cranes
b) Gross productivity of each crane
c) Total running hours per year, from which the maintenance and repair time has been deducted.

In addition to those three factors, waterside handing capacity should also be in line with the achieved yard handling capacity, ground transport capacity and yard storage capacity, because of two things. One thing is that any extra capacity over the bottleneck capacity is a waste of money. The other one is the limited buffer space besides each quay crane. Also sometimes a quay crane has to wait for a transport vehicle to pick up the container before taking on the next loading or unloading task. In the Business Model, the waterside handling capacity is calculated as follow:

$$\text{Waterside handling capacity} = \text{QC gross productivity} * \text{Maximum yearly operating hour} * \text{Amount of QC} \tag{4.7}$$

Ground transport capacity

Ground transport capacity is seldom a bottleneck for most contemporary container terminals, since the decisions made on vehicles are more or less flexible, and the turning buffers for vehicles are relatively easy to decide. The main decisive factors for ground transport capacity are similar to what we have seen above:

a) The number of vehicles
b) Gross productivity per vehicle
c) Total running hours per year, from which the maintenance and repair time has been deducted.

Yard capacity is determined by the yard handling capacity and storage capacity, which represent the two major functionalities of marine container terminals. The main issue is the balance between those two elements.

Yard handling capacity

Yard handling capacity is a performance indicator of yard handling equipment. Often it is determined by the following factors:

a) The amount of yard handling equipment.
b) Gross productivity per yard handling equipment; for instance, normally two RMG cranes are working parallelly with one dealing with containers at the waterside and the other one working at the landside. The gross productivity here is determined by the performance of waterside crane, given that the cranes in the water are much busier than the one in the other side.
c) Total running hours per year, in which the maintenance and repair time has been deducted.

In the terminal operation, waterside yard handling capacity is usually considered as the bottleneck of the yard handling capacity. It is calculated by using formula 4.8 in the Business Model.

$$WS\ yard\ handling\ capacity = ASC\ gross\ productivity * Maximum\ yearly\ operating\ hour * Amount\ of\ ASC \tag{4.8}$$

Storage capacity

Sufficient space should be planned to accommodate the projected throughput volume. The required area is defined by the number of terminal ground slots (TGS). The required TGS is determined by the following factors:

a) Project volume with cargo splits, transshipment percentage.
b) Dwell time.
c) TEU factor
d) Peak factor
e) The average stacking height, which depends on the type of handling equipment used in the yard.
f) The density of stacking area, which stands for the maximum density of stacking area in an operational perspective.

With a limited area of land available for stacking, a tradeoff between storage capacity and yard handling capacity has to be made. Taking RMG solution as an example, employing more RMG modules in the same stacking area, higher yard handling capacity can be provided, less storage capacity can be achieved, because of the fact that each RMG module requires a certain area for crane movement and rails. It is calculated by using formula 4.9 in the Business Model (see also Saanen, 2004).

$$Yard\ storage\ capacity\ per\ year = \frac{Amount\ of\ TEU\ ground\ slots * Stacking\ height * Terminal\ operating\ days\ per\ year * Stacking\ density}{Dwell\ time * Peak\ factor} \tag{4.9}$$

After having implemented the above aspects in the Business Model, a bottleneck analysis was performed. The results of this analysis are shown in Figure 4-11 and Figure 4-12.

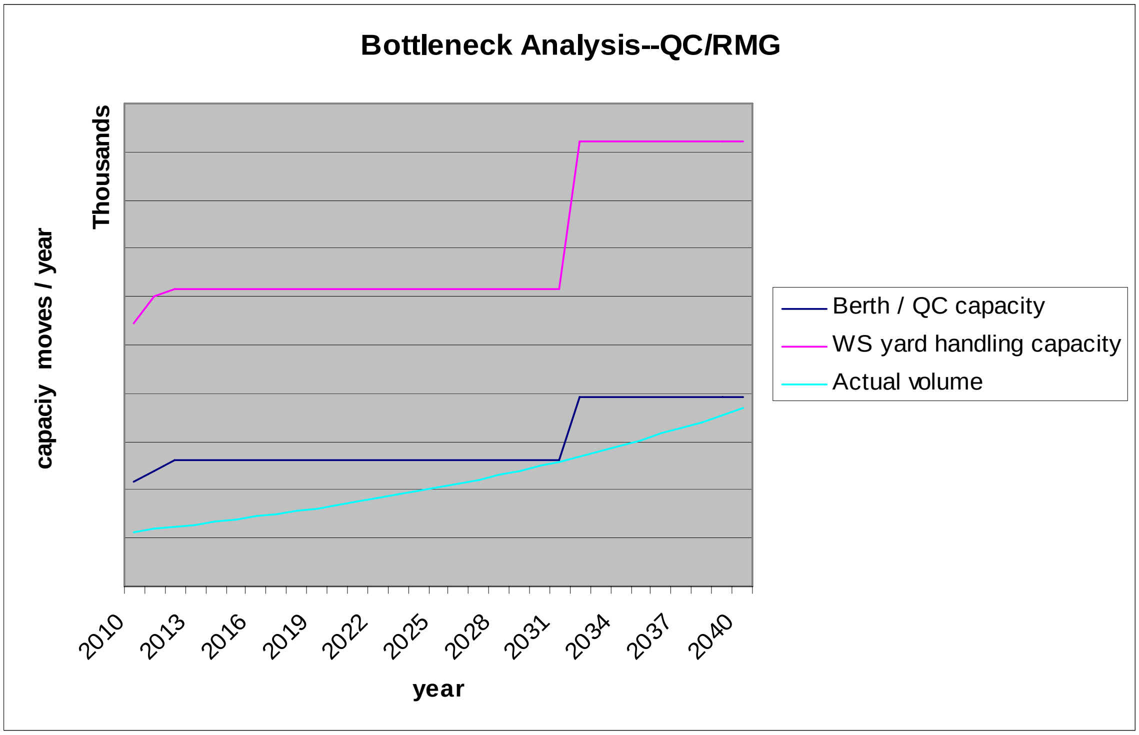

Figure 4-11 Bottleneck analysis based on moves (All the numbers here are for example only; they do not represent the actual figures)

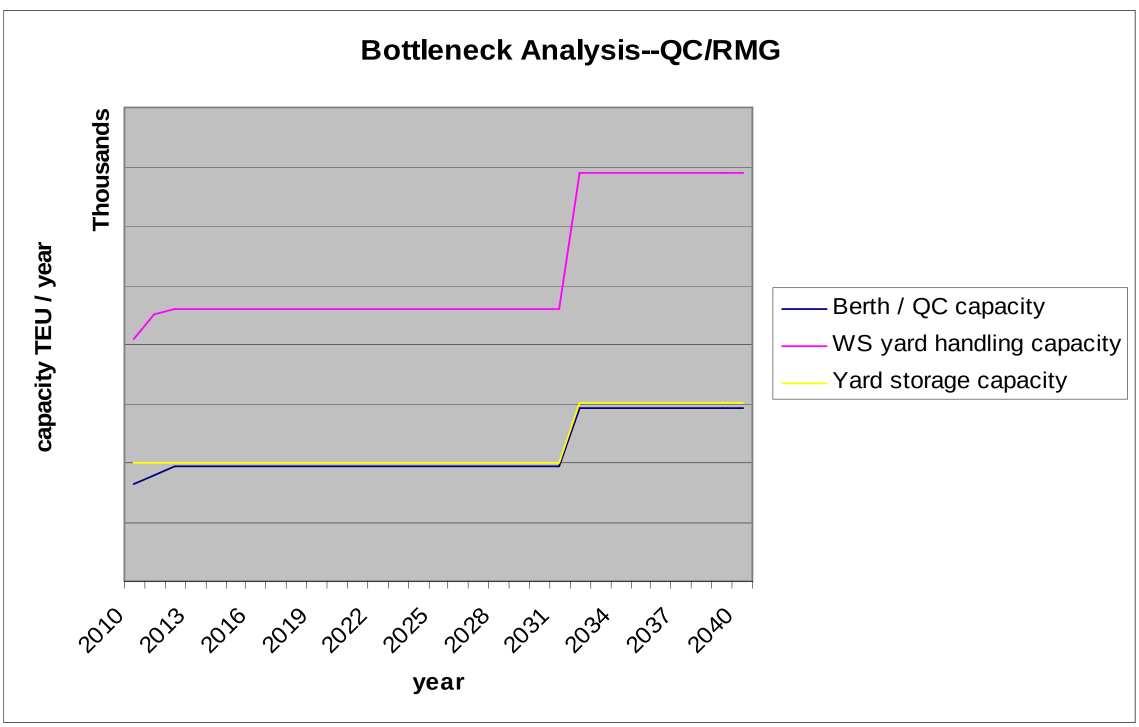

Figure 4-12 Bottleneck analysis based on TEU (All the numbers here are for example only; they do not represent the actual figures)

Figure 4-11 shows berth capacity and waterside yard handling capacity versus the projected volume (called actual volume in both graphs). It is shown that waterside yard handling capacity is much more than enough to handle the projected volume, while berth capacity is the bottleneck in the terminal. People who use this graph should be really careful if the volume growth is greater than the projected one, especially, for the year 2033 when berth capacity nearly equals the projected volume in the graph.

Figure 4-12 presents the berth capacity, waterside yard handling capacity and yard storage capacity on a TEU based. It is shown that the storage capacity is only slightly larger than berth capacity.

4.4.4 Graphical view of container moves and summary of moves by category

As a response to user's requests, a graphical view of moves and table summary for each category of moves were added to the Business Model (see Figure 4-13, Table 4.2).

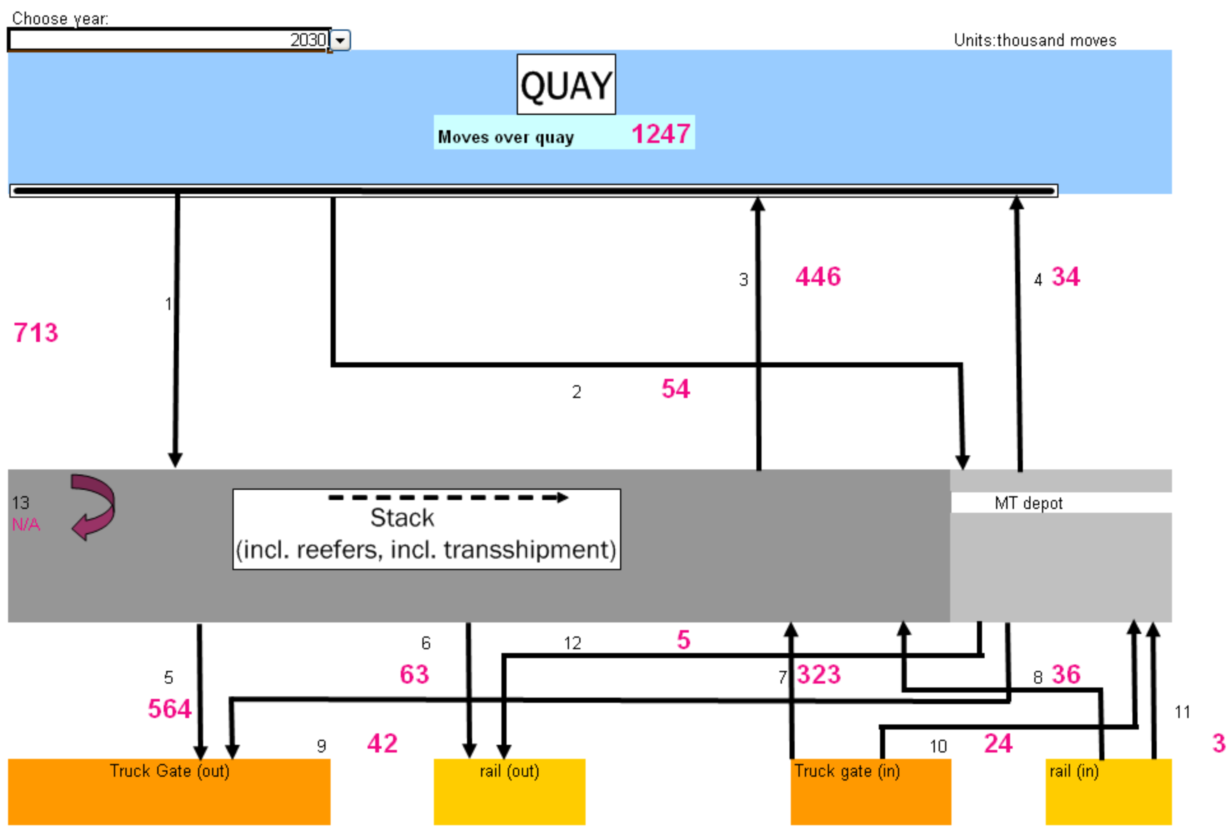

Figure 4-13 Moves in the terminal (Source: Presentation of Business Model of APMT, 2007. All the numbers here are for example only; they do not represent the actual figures)

The arrows in Figure 4-13 indicate the flows of container moves happening in a terminal. The numbers associated with those arrows represent the moves as follows:

1. quay to stack
2. quay to MT depot (is the place only for storing empty containers)
3. stacks to quay
4. MT depot to quay
5. stacks to truck gate
6. stacks to rail
7. truck gate to stack
8. rail to stack
9. MT depot to truck gate
10. truck gate to MT depot
11. rail (in) to MT depot
12. MT depot to rail (out)

As long as the year has been chosen (see left top of Figure 4-13), the number of moves will be presented in the above graph in the unit of one thousand moves. Along with Figure 4-13, a table summarizing the gate moves, rail moves, quay moves and transshipment moves is provided in the new Business Model (see Table 4.2).

Table 4.2 Summary of moves by category (All the numbers here are for example only; they do not represent the actual figures)

	Summary: moves		
year	2030	Units:	thousand moves
	Import	Export	Total
Landside			
Rail	39	67	106
Truck	348	606	954
Total	386	673	1,060
Waterside			
Moves over quay			1,247
Quay moves (TS)			187
Quay moves (Excl. TS)	386	673	1,060

4.4.5 Graphs showing the utilization of terminal area

The utilization of the terminal area is important information for BDV mangers to decide the phasing of construction and choose the mode of operation, since the area for marine container terminals is precious, especially in Western Europe and North America (said by APMT professionals), and since different modes of operation require different amounts of space to accommodate the same amount of volume. The different amount of space required is because the operational stacking density in each mode of operation is varies per mode. For instance, containers can be stacked closer when a RMG module is used than when a SC is used. It is also required by the user to graphically show the utilization of the terminal area during the development of the Business Model. Figure 4-14 shows the new functionality of showing the utilization of terminal land by graphs.

The user is able to choose a year and a mode of operation (see left top of Figure 4-14) to observe the land utilization for that combination. In the shown example, the user wants to observe the land utilization in the year 2011, if SC has been chosen. In the first graph in Figure 4-14, the total available area, facilities area, quay length, required marine apron and stack area, and the unused area are shown clearly. Associated with the first graph, the second one shows the percentage of each category of land over the total available area.

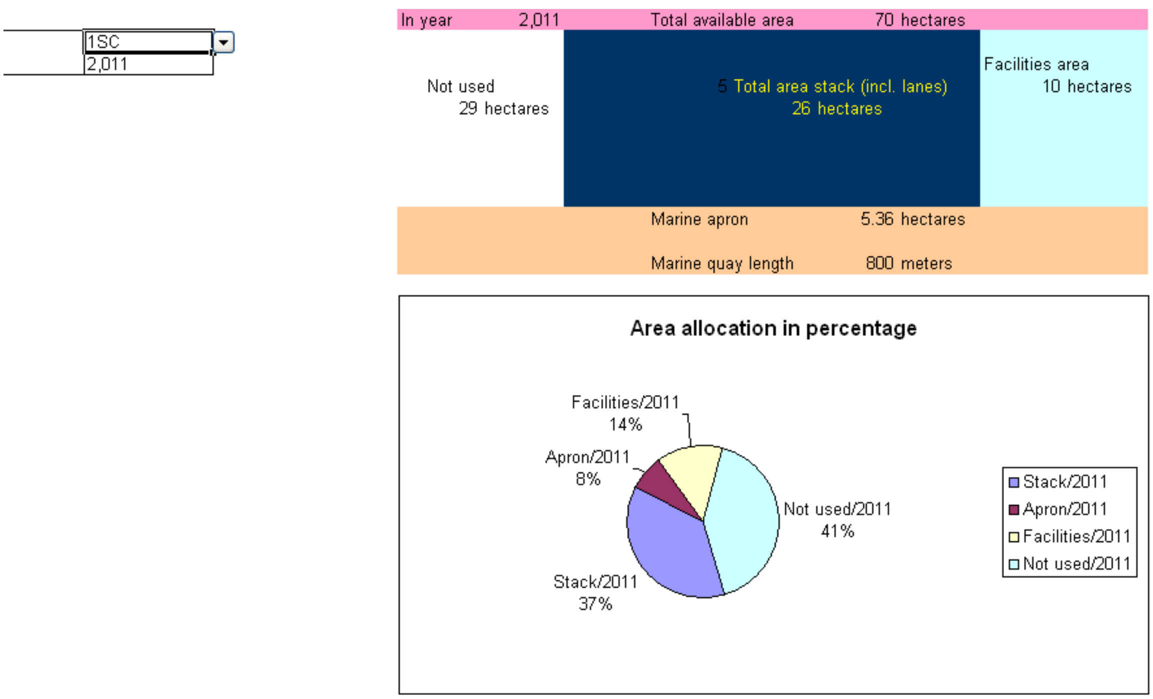

Figure 4-14 Utilization of terminal area (All the numbers here are for example only; they do not represent the actual figures)

In this section, improvements were described, aiming to improve the accuracy of the calculation and the usability of the Business Model. Adding the functionality of sensitivity analysis as an important part of this research, will be explained in detail in the next chapter.

5 Sensitivity Analysis

The recommendation of an optimal mode of operation is made based on the analysis of costs in the Business Model. It is based upon the default-input parameters, which have been agreed upon within APMT. However, there could be some uncertainties on those default-inputs, unclear specifications or changes of project settings.
In order to decide for either the human-based or one of the automated terminal concepts it appears to be of great interest to investigate the sensitivity of the total cost for some major responsible parameters. In this chapter, a brief introduction about sensitivity analysis is presented in section 5.1. The techniques and process of sensitivity analysis will be presented in section 5.2 and 5.3 respectively. The limits of uncertain parameters will be defined in section 5.4. A description of the results of sensitivity analysis will be indentified in section 5.5. Finally, conclusion and recommendation will be given at the end of this chapter.

5.1 Introduction Sensitivity Analysis

Different interpretations of Sensitivity analysis are used in different modeling communities (see Turanyi and Rabitz, 2000; Varma, 1999; Goldsmith, 1998; Helton, 1993). Quite often, “sensitivity analysis is identified almost as a mathematical definition, with a differentiation of the output with respect to the input. In more general terms, uncertainty and sensitivity analyses investigate the robustness of a study when the study includes some form of mathematical modeling (Saltelli et al. 2006).” Sensitivity analysis has been used in a vast range of research, including atmospheric chemistry (Campolongo and Saltelli, 1999; Campolongo and Tarantola, 1999), transport emissions (Kioutsioukis, 2004), fish population dynamics (Zaldivar, 2000), composite indicators (Tarantola, 2000), portfolios (Campolongo, 2004), oil basins models (Saltelli, 2002), radioactive waste management (Saltelli and Tarantola, 2002), geographic information systems (Crosetto, 2001), solid-state physics (Pastorelli, 2000). Applications from several practitioners can be found in (Saltelli, 2000), and in several special issues in the specialized literature (Saltelli, 1999; Frey, 2002). Sensitivity analysis is also used within APMT to address the risk of implementing a project (APMT, 2002).

The benefits of sensitivity analysis are mainly the following (Eschenbach, 1989):

1. Making better decisions,
2. Deciding which data estimates merit refinement,
3. Focusing managerial attention on the key variables during implementation.

5.2 Techniques for sensitivity analysis

Sensitivity analysis is abroad term that includes a variety of techniques. Two techniques are found to be the most suitable ones in this research: Tornado diagram and Spider plots.

Tornado diagrams:

Tornado diagrams graphically display the result of single-factor sensitivity analysis. A typical diagram looks like Figure 5-1, which shows the effect of four parameters on the result. The parameters are sorted from the one having the largest influence at the top and the one having the smallest influence at the bottom.

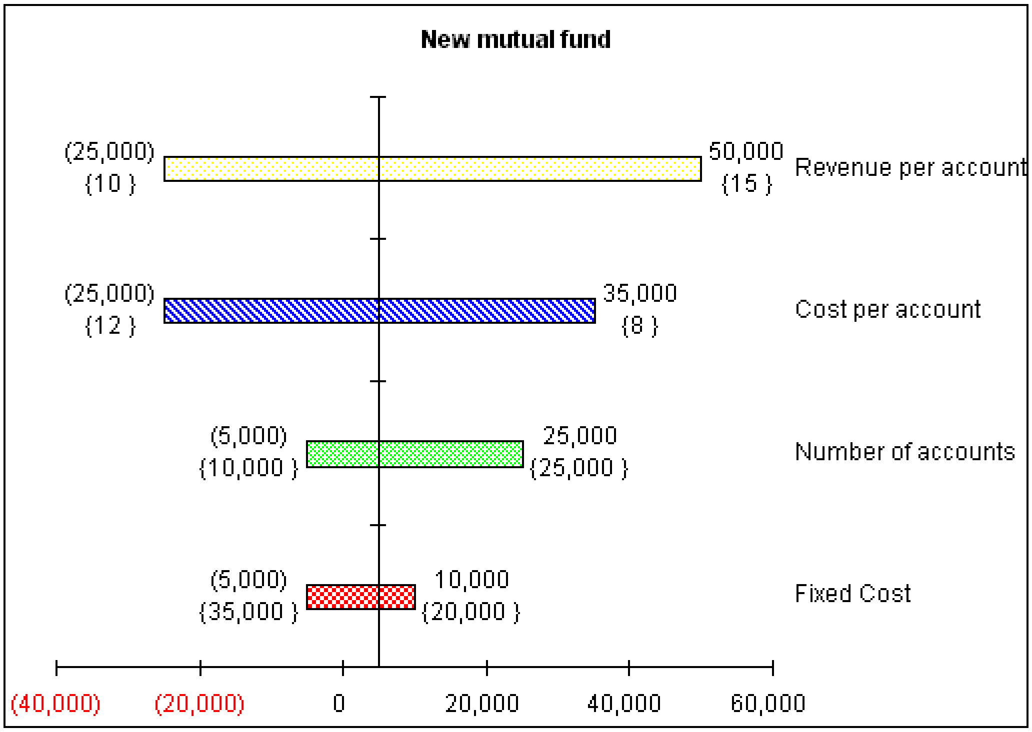

Figure 5-1 Example of Tornado diagram (Source: http://www.tushar-mehta.com)

The horizontal position of each parameter relative to the y-axis corresponds to the parameters being at its respective nominal or base value. For each of the uncertain decision parameters, the chart contains one horizontal bar and two sets of numbers, one of the left and the other to the right of the bar. Each set of numbers corresponds to the result value (upper number) and the value of the parameter at which the result value was reached (the lower number within curly brackets). Negative numbers are shown in parenthesis.

Spiderplots:

A properly drawn spiderplot depicts the following three things:

1. Limits of uncertainty for each parameter
2. Impact of each cash flow element on the Present Value
3. Identification of which cash flow elements might change the recommendation

On a spiderplot (see Figure 5-2), there are two directions to measure uncertainty. On the x-axis, the potential uncertainty in the parameter is measured in a common unit: the percentage of each base case value. On the y-axis is measured the impact of that uncertainty on the observed value is given.

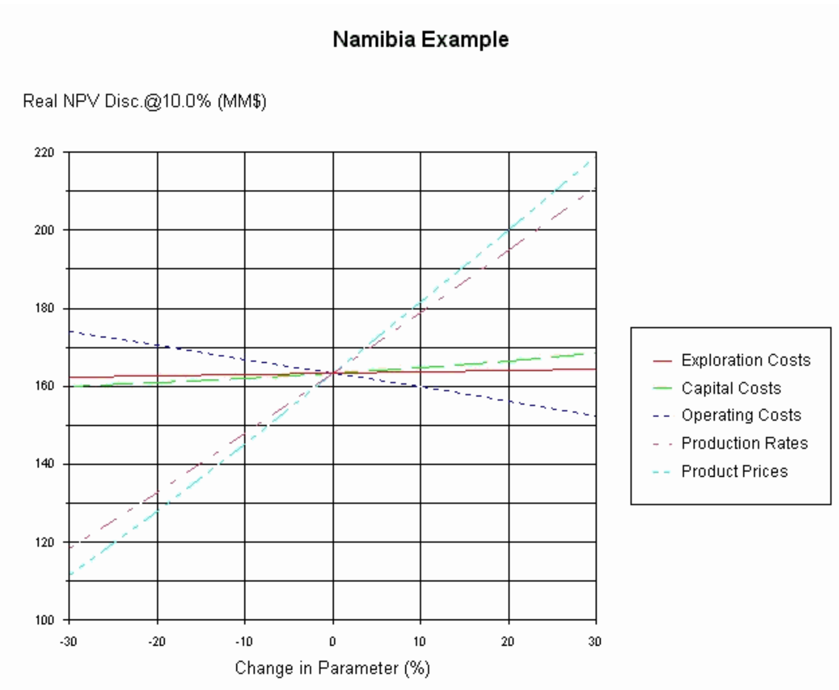

Figure 5-2 Example of Spiderplot (Source: http://www.dfass.demon.co.uk)

5.3 Process of sensitivity analysis

Sensitivity analysis examines how a recommended decision depends on estimated parameters. The first step of sensitivity analysis is selecting the uncertain parameter. Following that, the limits of uncertainty for each parameter should be defined. The next step is to apply techniques of sensitivity analysis to answer how a recommended decision depends on estimated input variable values (see Figure 5-3).

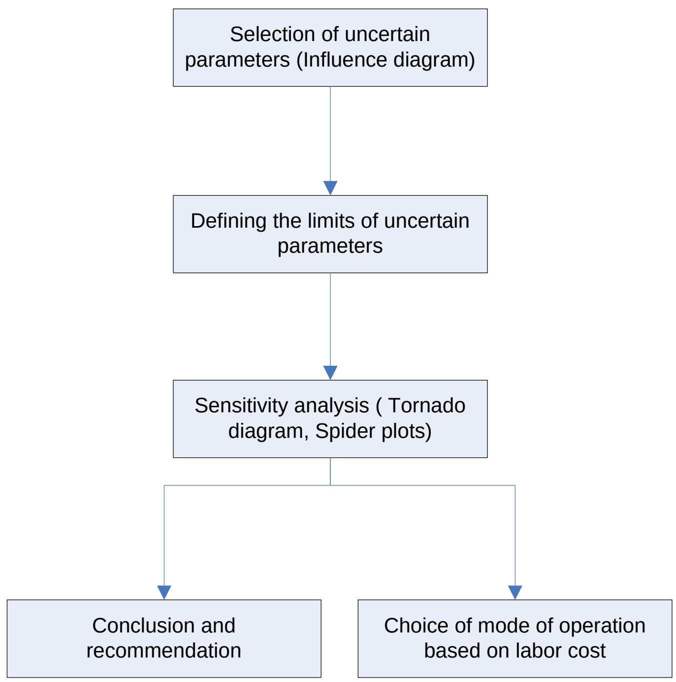

Figure 5-3 Framework of sensitivity study

5.4 Selection of screened parameters

The first step of sensitivity analysis is selecting parameters having uncertainty on their estimated value. The purpose of sensitivity analysis for the Business Model is to examine how the total cost varies along with the changes of its input parameter. Therefore, the selection of those parameters should comply with the following rules:

- The parameter has important influence to the cost.
- The parameter has a big uncertainty for its estimated value.

In addition to the proposed rules, experts' suggestion will be also taken into account.

In order to judge the importance of a parameter to the total cost, there are two types of diagrams which can be used. One is the diagram which shows the cost composition provided by the Business Model (see Figure 5-4, Figure 5-5). Another one is so called influence diagram, which is a visual representation of the model.

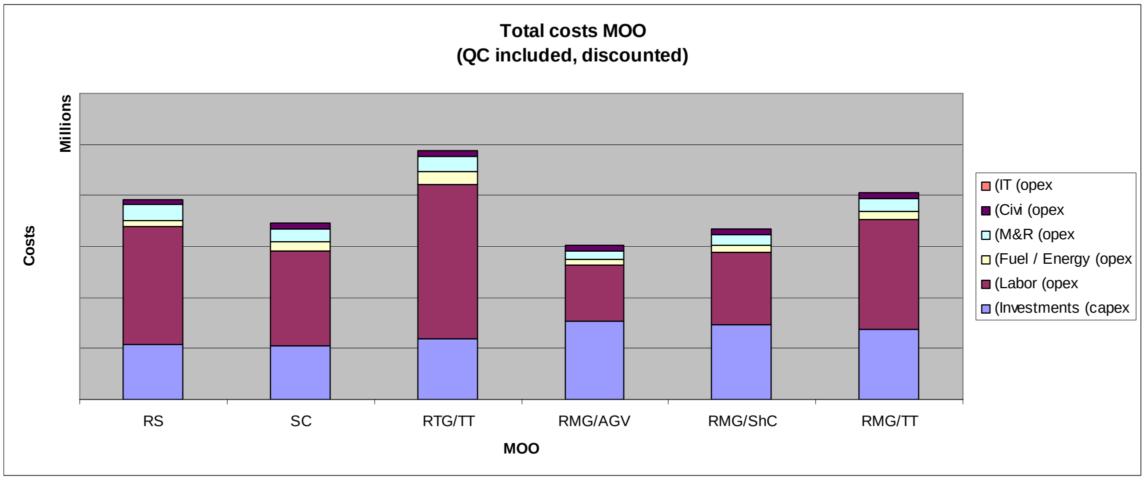

Figure 5-4 Components of total cost for each MOO (All the numbers here are for example only; they do not represent the actual figures)

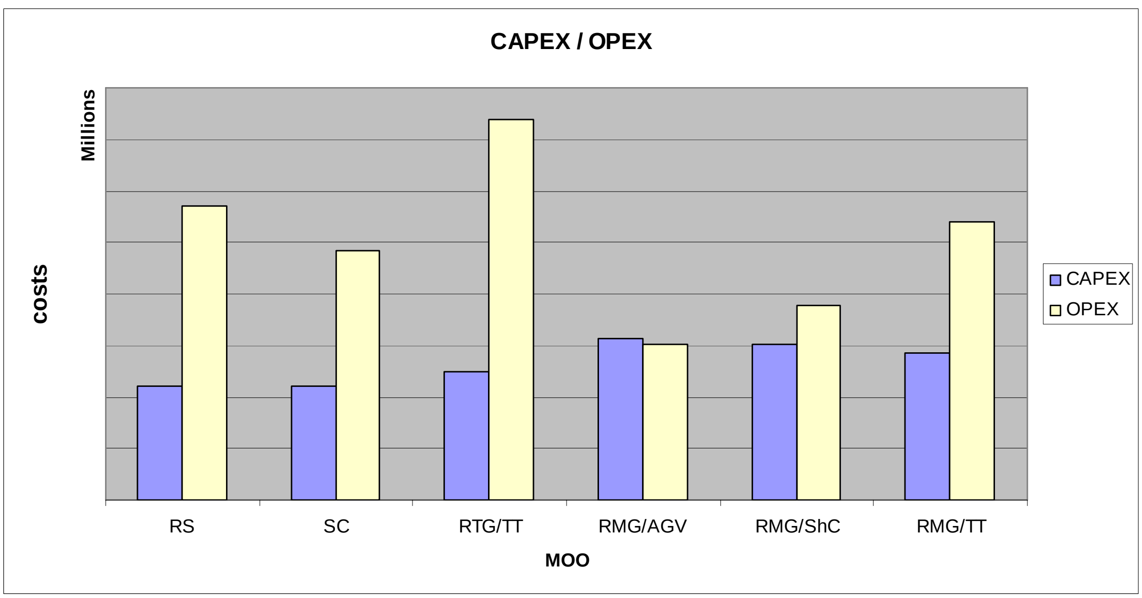

Figure 5-5 CAPEX and OPEX for each MOO (All the numbers here are for example only; they do not represent the actual figures)

Figure 5-4 and Figure 5-5 show the cost components for each mode of operation with the default value of the input parameters. The OPEX is larger than the CAPEX in the human-based mode of operation, while the OPEX and CAPEX are quite close in the automated mode of operation. The result is reasonable because that the automated equipment requires a high investment at the beginning but low operating cost since it has higher efficiency and less manning practice than the human-based equipment. The labor cost shown in Figure 5-4 only includes the blue collar labor cost, and the labor cost for M&R are counted in the category of M&R cost. Obviously in Figure 5-4, the labor cost is the main component of the OPEX in each mode of operation. This result is also in line with the finding in other research, which indicate the labor cost of the total operational cost varies between 35% (Far East) towards 50% (Northwest Europe) and 65% (USA, West coast) (Dobner, 2001; Saanen, 2001). Other components of OPEX such as IT cost, M&R cost, civil cost and energy cost are not seen as important elements. Therefore, sensitivity analysis will focus on the CAPEX components and the labor cost.

An influence diagram is a useful technique that allows the model to be built in parts, and for the effects of various parts to be seen without getting immersed in the details of the model. The outcome of the influence diagram is a picture of the dependent and independent variables, and the relationship between them (see Figure 5-6).

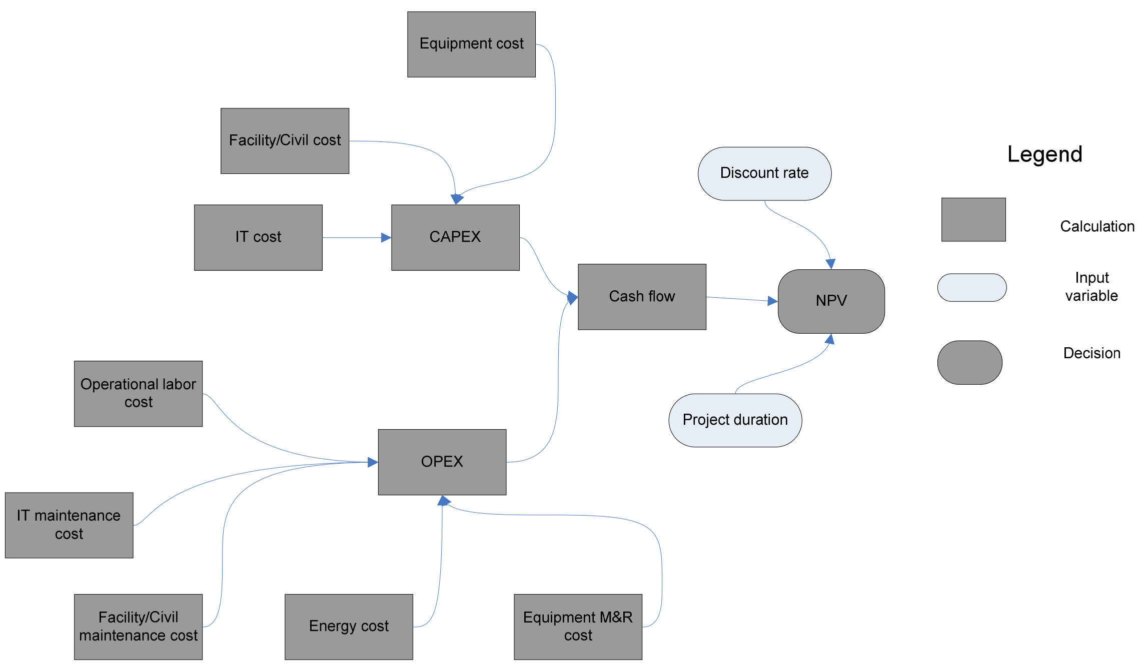

Figure 5-6 First level of influence diagram

Figure 5-6 show the first level of an influence diagram representing the total cost in the Business Model. In that picture, decision variables which are the NPV of some cost are marked as rectangles with rounded corners, interim results based on calculations are marked as rectangles and the input variables are marked as ellipses. As discussed above, the analysis will focus on the components of CAPEX that includes equipment cost, facility cost and IT cost, and the OPEX component which is labor cost. The influence diagrams for those four components are draw below:

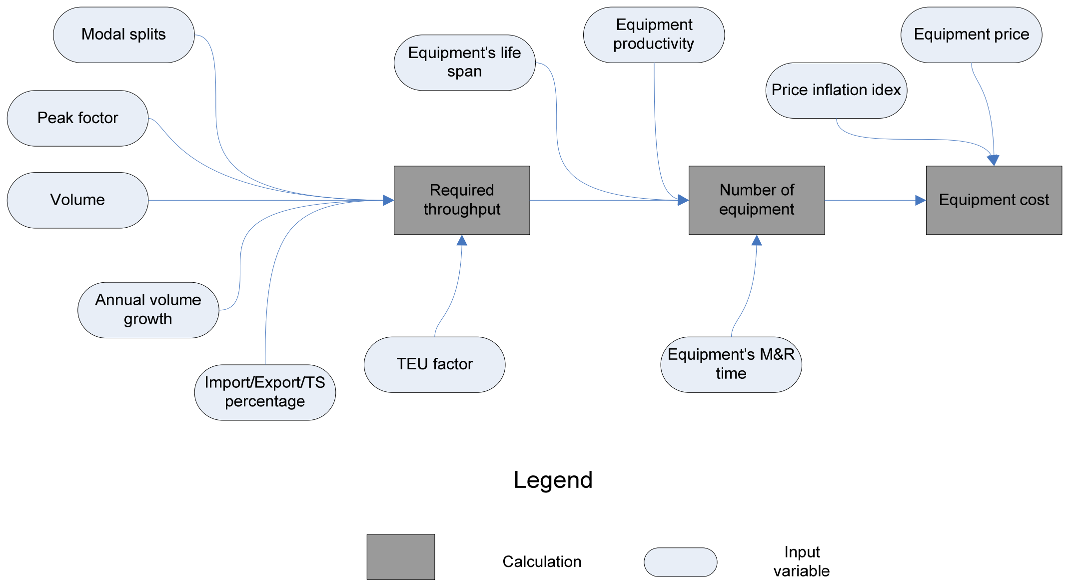

Figure 5-7 Influence diagram for equipment cost

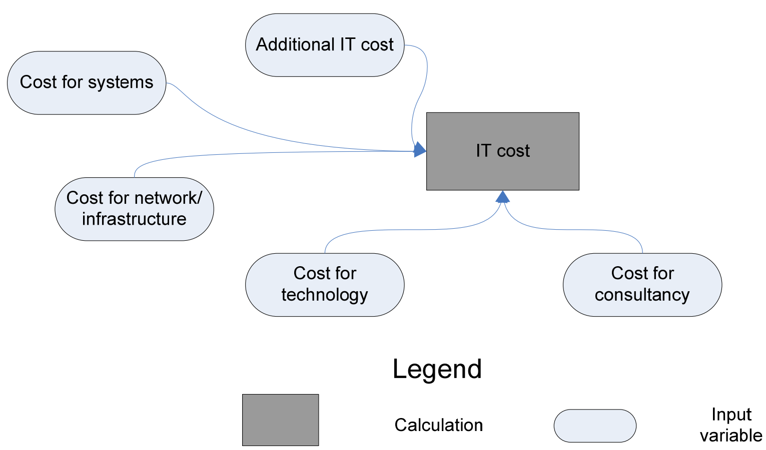

Figure 5-8 Influence diagram for IT cost

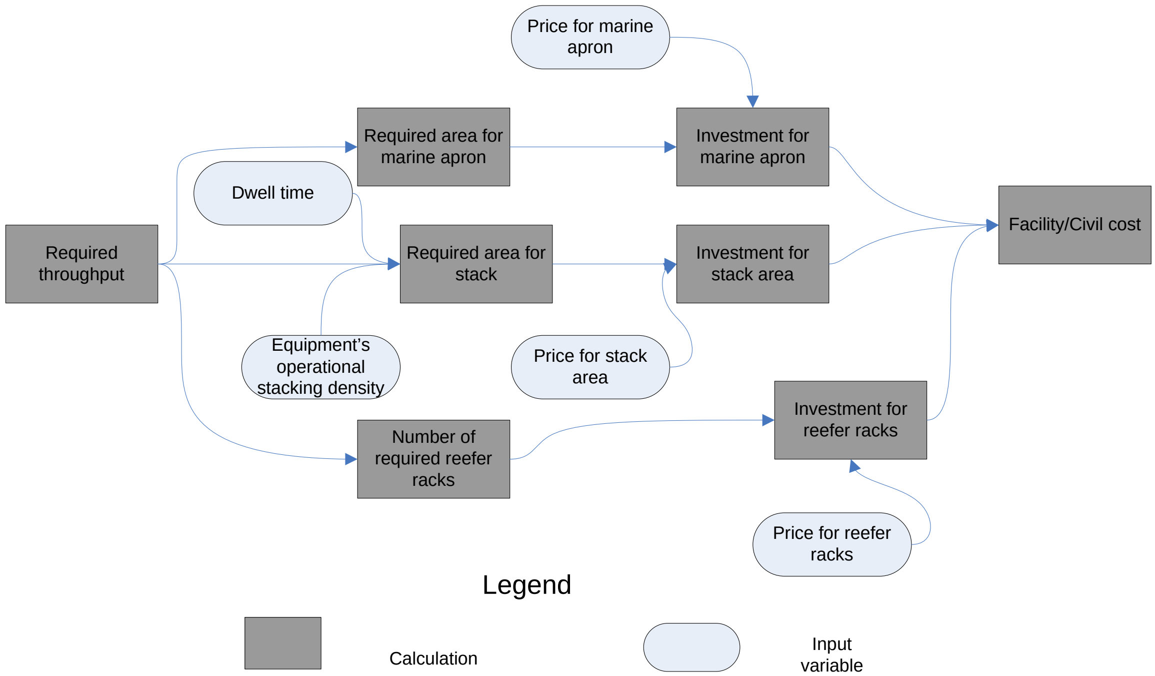

Figure 5-9 Influence diagram for facility/ civil cost

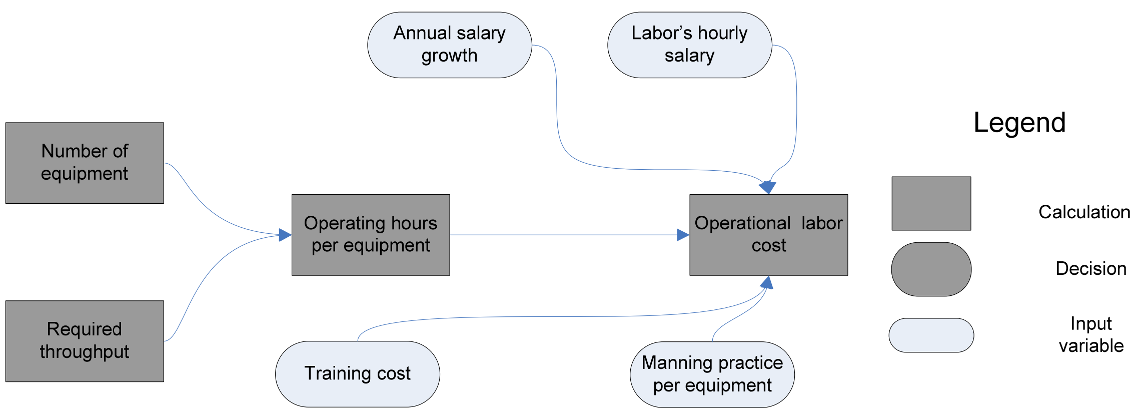

Figure 5-10 Influence diagram for operational labor cost

The variables associated with those main cost components are identified in the above figures. Those variables can be the candidates for use in sensitivity analysis. But not all of those variables will be selected; only the ones with quite a big uncertainty when making the estimation will be selected. The fact is that there is little historical data which can be used as the base to make estimation for its future value, such as for TEU factor, modal splits, peak factor. Many input variables are based on either operational experience, such as IT cost, equipment's M&R time, equipment life span, or an industrial benchmark, such as stacking density for each mode of operation and manning practice per equipment.

There are also some monetary variables which are gathered from a stable market such as price for marine apron, stack area and reefer racks. In addition to the project duration, which is also decided when starting a business case, all the above variables have a little uncertainty when estimating their value, and they will not be taken into account in sensitivity analysis. However, there are some variables bearing a volatile future for which no historical data are available to be used to estimate their future value, such as volume, dwell time, labor cost, discount rate, equipment price. Those variables will be focused on in sensitivity analysis.

Energy price and equipment productivity is also considered when selecting the variables based on expert's suggestion. Energy price has a big tendency to fluctuate resulting from the uncertainty of the global market and political issues; people would like to see its influence on the choice of mode of operation. The default value of equipment productivity in the Business Model is based on the estimation of the equipment's operational productivity, which may be different from the gross productivity which is used to calculate the amount of equipment required (see section 3.5).

By considering the importance and uncertainty of each variable and the expert's suggestion, the following variables are selected for sensitivity analysis:

- Volume
- Annual growth
- Dwell times
- Discount rate
- Blue collar
- Annual salary growth
- Equipment productivity
- Equipment price
- Equipment price index
- Power price
- Power price index
- Fuel price
- Fuel price index

5.5 Defining the limits of uncertain parameters

Once the variables have been chosen, their limits should be defined. Often, these uncertainties are stated as percentages of the most likely values (the default value in the Business Model). For example, the cost of purchased equipment might be known within ± 20%, or between 80% and 120%, of the most likely value.

Often, the limits on the uncertain data are asymmetrical, because there seem to be more ways for things to go wrong than for things to go right. Thus, cost are more likely go up than down and delays until start-up are more likely to be longer than shorter.

The limits for each variable are presented in the Table 5.1.

Table 5.1 Uncertainties in the data for the Business Model (All the numbers here are for example only; they do not represent the actual figures)

Variable	**Unit**	lower limits	Upper limits
QC price	US$	80%	130%
QC productivity	mph	50%	150%
Volume	moves / year	50%	150%
Annual growth	%	50%	150%
Equipment price index	%	50%	150%
Power price	US$ / kWh	50%	150%
Power price Index	%	50%	150%
Fuel price	US$ / Liter	50%	150%
Fuel price Index	%	50%	150%
Dwell times	days	50%	150%
Discount rate	%	50%	150%
Blue collar	US$ / hours	50%	150%
Annual salary growth (%)	%	50%	150%
SC price	US$	80%	130%
RTG price	US$	80%	130%
RMG price	US$	80%	130%
TT price	US$	80%	130%
AGV price	US$	80%	130%
ShC price	US$	80%	130%
SC productivity	mph	50%	150%
RTG productivity	mph	50%	150%
RMG productivity	mph	50%	150%
TT productivity	mph	50%	150%
AGV productivity	mph	50%	150%
ShC productivity	mph	50%	150%

Since there are no historical data in APMT to track the changes of those variables in the past, it is not possible to define the limits by using a data analysis technique such as a regression model. Two ways are followed in defining those limits within this research:

- AACE's standard on cost estimation

  The American Association of Cost Engineers (now AACE International) defines three kinds of estimates, which are done in order as a project progresses (Humphreys et al. 1987). The first is an order-of –magnitude estimate, the second a budget estimate, and the third a definitive estimate. Even when these estimates are done properly, actual costs rarely match the estimates. The reasonable range for actual costs around the estimated value is:

Table 5.2 Reasonable range for actual costs around the estimated value (Eschenbach, 1989)

Estimate Type	Actual vs. Estimate
Order-of -magnitude	-30% to + 50%
Budget	-15% to + 30%
Definitive	-5% to + 15%

  The estimation of the price for each type of equipment belongs to the budget estimate, and therefore the limits of those variables are set between -20% and + 30% of the based value, since the price of these equipment is more likely go up than down.

- Other practice on sensitivity analysis within APMT

  Sensitivity analysis used to be conducted within APMT to address the risk in other projects as well (APMT, 2002). A range from -50% to +50% was taken for each estimated variable. Therefore, the limits for other variables within this research are decided to follow the same range as in other APMT projects.

In order to reduce the potential for bias of using the sensitivity analysis, the limits are estimated before the basic result is calculated. That is because if the result calculated first, then someone might be tempted to use limits that support the "described" outcome. Also, if the limit is not "reasonable" with respect to the observed value, the sensitivity analysis will be quite misleading (Eschenbach, 1989).

5.6 Description of screening results

The graphical representation of the sensitivity analysis will use the two techniques discussed in section 5.2. Figure 5-11 presents the sensitivity of each variable to the total cost in the RMG/AGV solution. The impacts of each uncertain variable to the total cost of the RMG/AGV solution are listed from the top to the bottom in descending order in Figure 5-12.

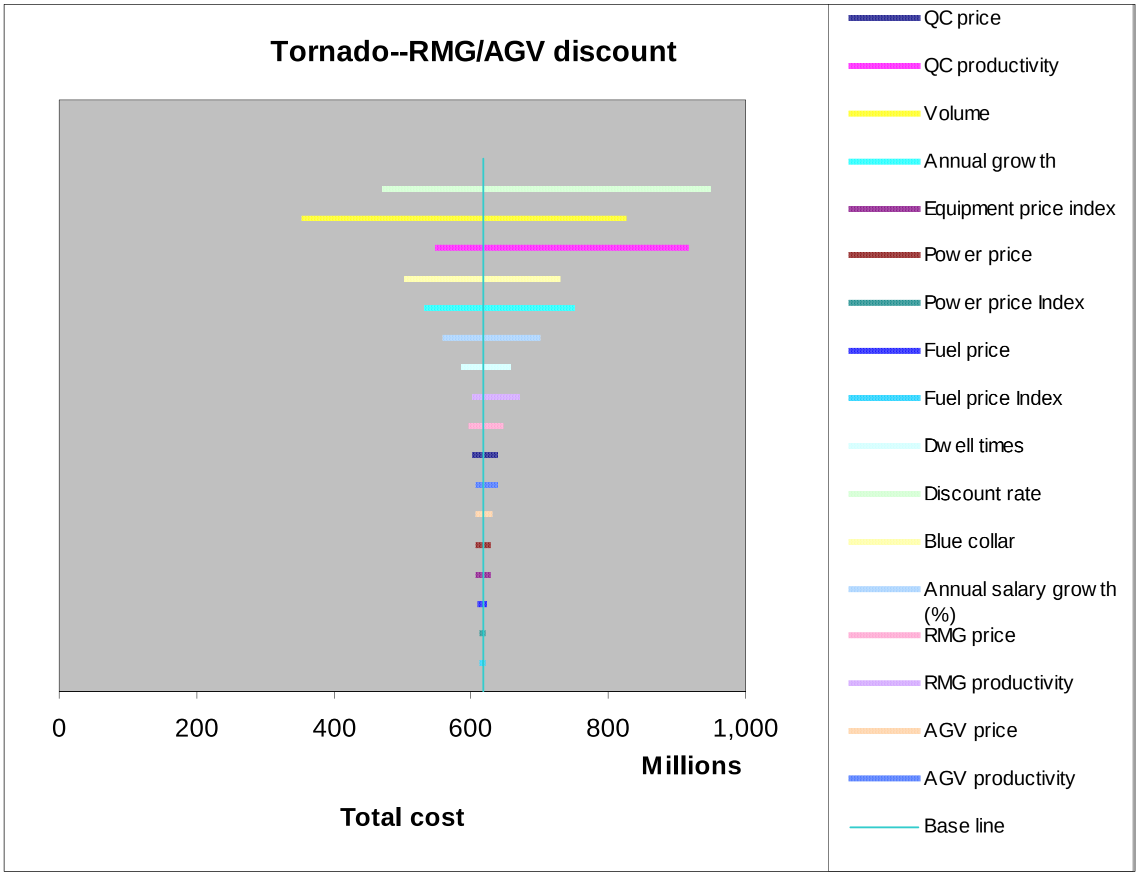

Figure 5-11 Tornado diagram for RMG/AGV solution (All the numbers here are for example only; they do not represent the actual figures)

The top five variables which have the biggest impact to the total cost are identified as follows:

- Discount rate
- Volume
- QC productivity
- Blue collar cost

- Annual volume growth

The uncertainty of the rest of the variables has small influence on the total cost, which means less focus should be put on uncertain variables when planning the business case: the changes of those variables will not change the decision.

The advantage of Tornado diagram is that it eases comparison when there are more than 7 variables, but it does not show the limits on each variable; therefore, a spiderplot is also used in this sensitivity analysis (see Figure 5-12 Spiderplot for RMG/AGV solution).

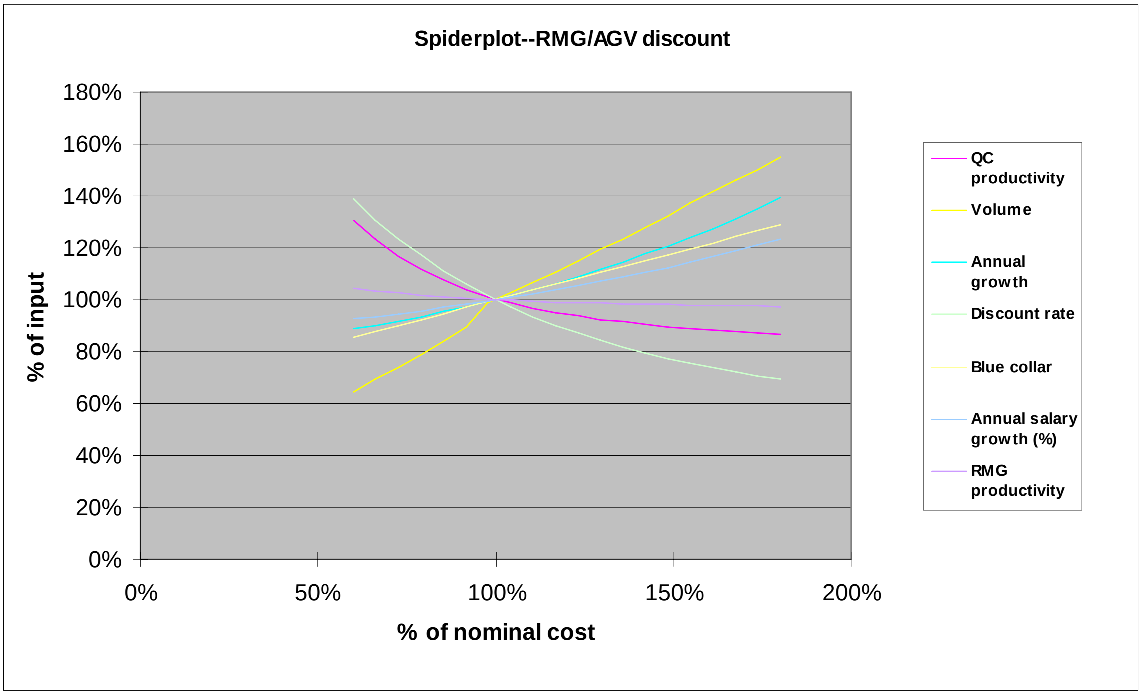

Figure 5-12 Spiderplot for RMG/AGV solution (All the numbers here are for example only; they do not represent the actual figures)

There seven curves are presented in the spiderplot, where more than seven curves will make it difficult to read. Within the limit from 50% to 150% of its based value, the uncertainty of discount rate, projected volume, QC productivity and blue collar labor cost bring the biggest influence to the total cost, namely the total cost is quite sensitive to the changes of those variables. The important variables for other modes of operations are also indentified by screening the Tornado diagram and Spiderplot for each of them (see appendix IV and V).

For the SC solution, the important variables were indentified as follows:

- Discount rate
- Volume
- Blue collar cost
- QC productivity
- Annual volume growth

For the RTG/TT solution, the important variables were indentified as follows:

- Discount rate
- Volume
- Blue collar cost
- Annual volume growth
- Annual salary growth

For the RMG/ShC and RMG/TT solution, the important variables were indentified as follows:

- Discount rate
- Volume
- Blue collar cost
- QC productivity
- Annual volume growth

Given the fact that the Business Model is aiming to choose the optimal mode of operation, the question how the uncertainty on those variables will influence the choice should be addressed. In order to answer that question, a graph can be used that shows the effect of a change of one variable to all modes of operation.

Sensitivity on the development of volume and annual volume growth rate

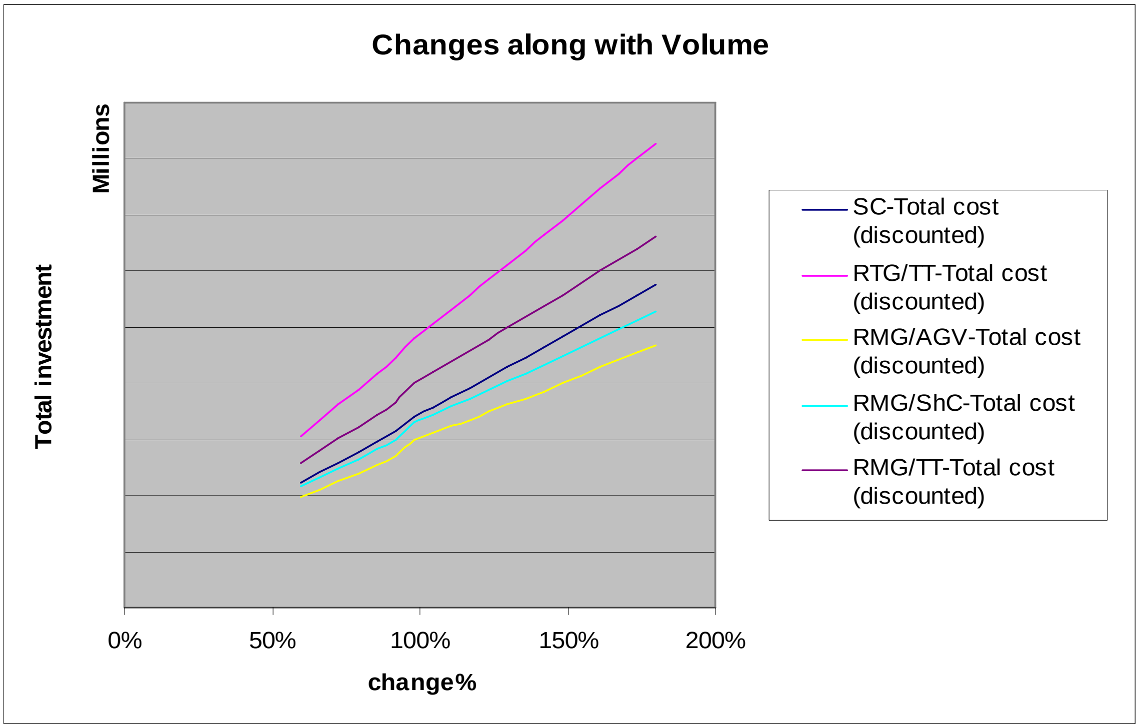

Figure 5-13 Sensitivity on the development of volume (All the numbers here are for example only; they do not represent the actual figures)

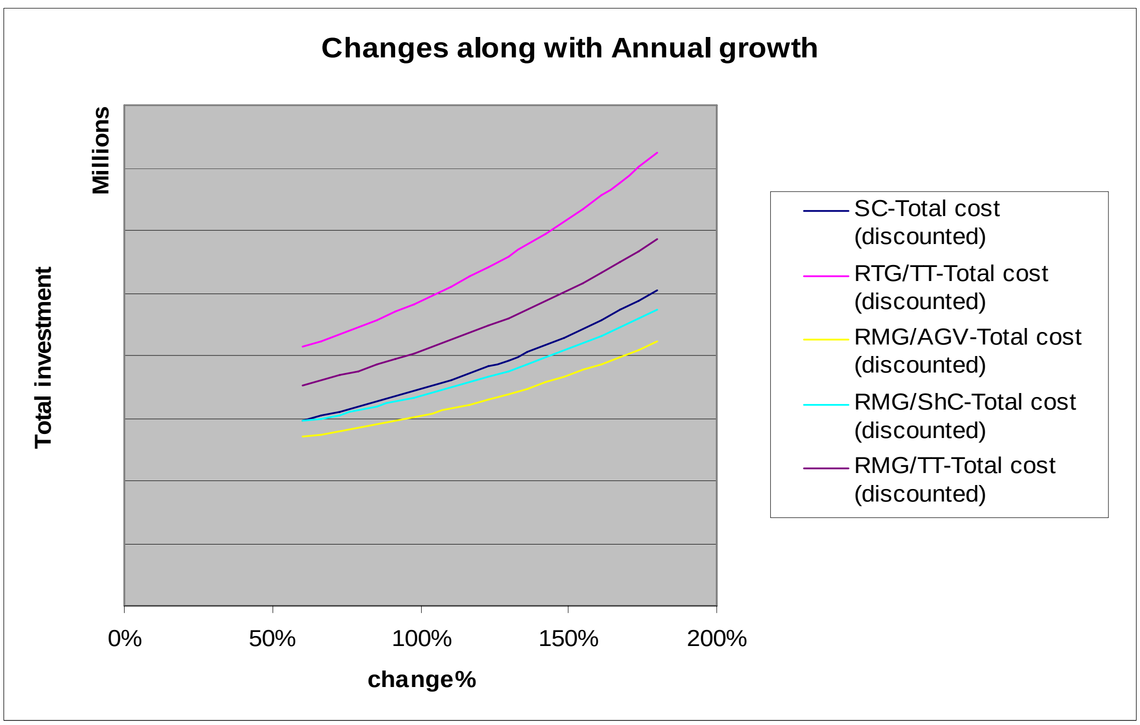

Figure 5-14 Sensitivity on the development of annual volume growth rate (All the numbers here are for example only; they do not represent the actual figures)

Figure 5-13 and Figure 5-14 show the influence of changes in volume development on the choice of a mode of operation. It is shown that with a 50% decrease or a 50% increase on the base value of the projected volume, the optimal mode of operation stays the same. However, the automated mode of operation (RMG/AGV) shows more economical advantages with actual volume increase in the future, because of the fact that changes of the total cost in using the human-based mode of operation is nearly twice of the changes when using the automated mode of operation.

Sensitivity on the development of discount rate

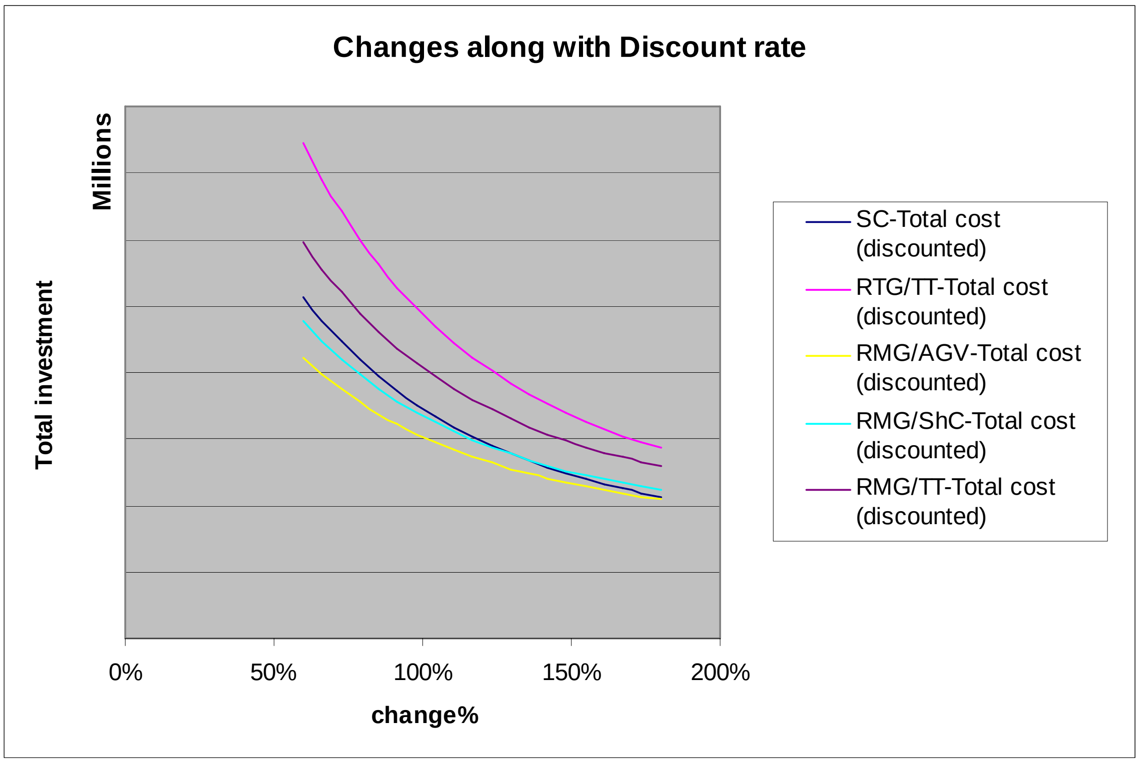

Figure 5-15 Sensitivity on the development of discount rate (All the numbers here are for example only; they do not represent the actual figures)

Discount rate is also an important variable influencing the cost sensitivity. Changes of the discount rate within the limits of its uncertainty do not affect the choice of mode of operation (see Figure 5-15). The automated mode of operation looks promising, even though the difference of the total cost between each mode of operation is getting smaller along with the increasing value of discount rate. If we recall the composition of the total cost for each mode of operation, OPEX is the biggest component. Therefore, the OPEX for human-base mode of operation will be affected more by the discount than the OPEX for the automated mode of operation.

Sensitivity on the development of blue labor cost and salary growth rate

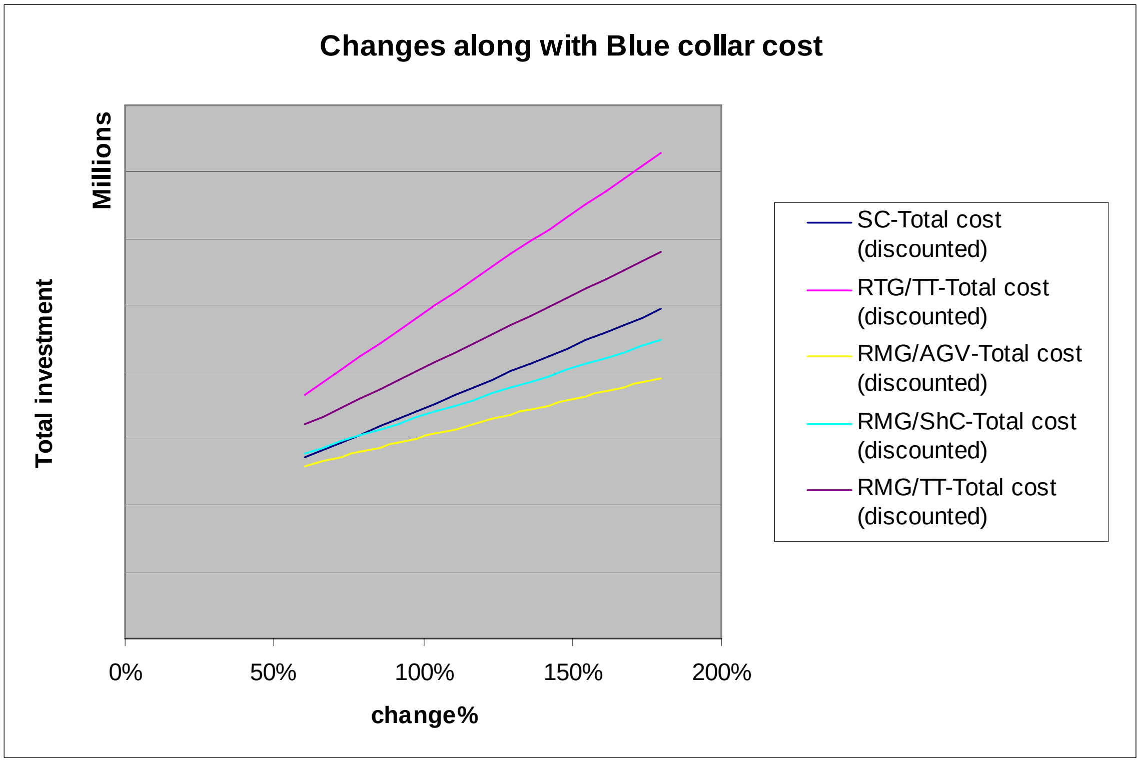

Figure 5-16 Sensitivity on the development of blue labor cost (All the numbers here are for example only; they do not represent the actual figures)

The most sensitive variable concerning the operating cost is the labor cost for blue collar per man-hour. The graphs are Figure 5-16 and Figure 5-17 illustrate that the dependency of the human-based operation on unforeseen changes in salaries and salary growth is far higher than in the automated operation. The cost saving of automated terminals is extraordinary high, which is twice that of the human-based operation.

However, even though the automated operation seems more and more attractive for the terminals operation in North America and Western Europe, the human-based is still preferred in the area where the labor cost is extraordinarily cheap. The point at which the labor cost can guide the choice of mode of operation is presented in Figure 5-18. It is demonstrated that if the labor cost per man-hour is lower than a certain value ($A in Figure 5-18), then the human-based operation is much more cost efficient than the automated operation, while the reverse is true when the labor cost is greater than a certain value ($B in Figure 5-18). Between $A per hour to $B per hour, there is no significant difference in the total cost between the two modes of operation.

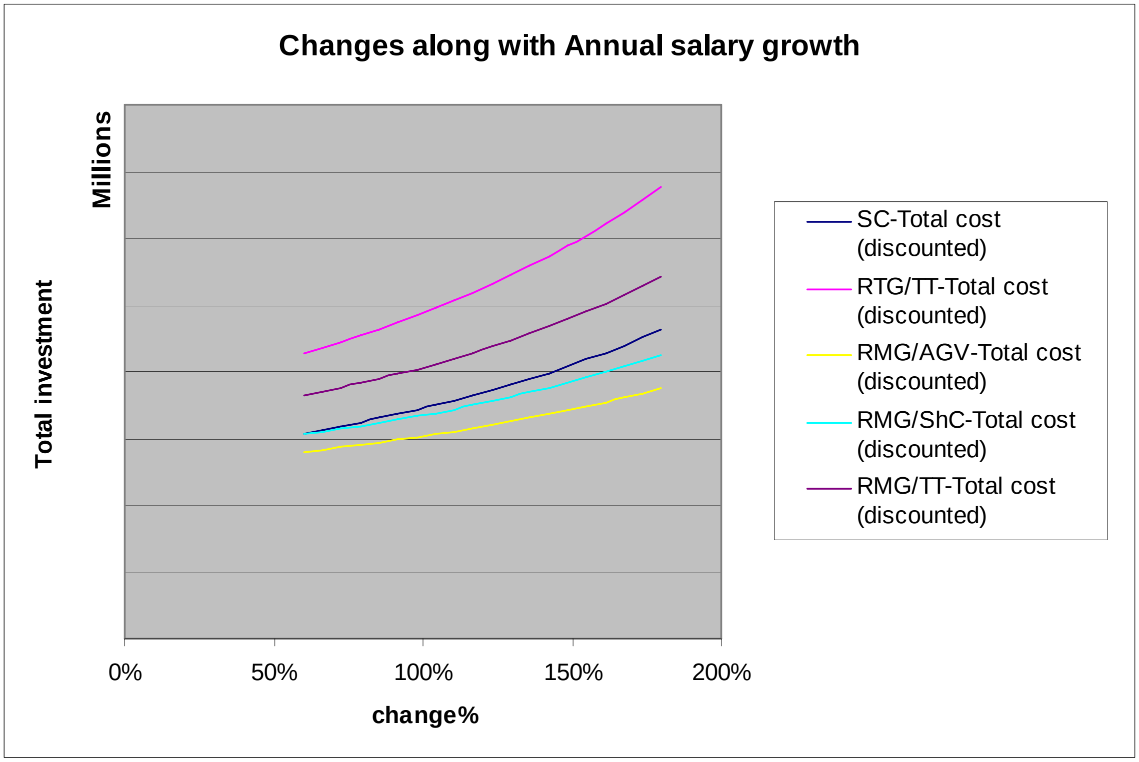

Figure 5-17 Sensitivity on the development of salary growth rate (All the numbers here are for example only; they do not represent the actual figures)

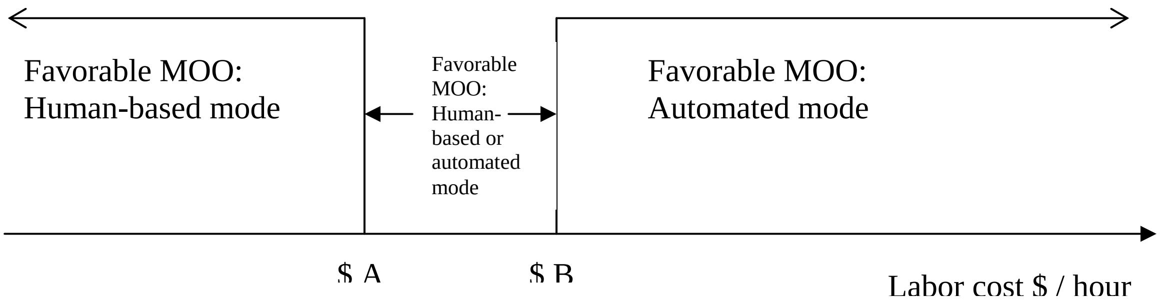

Figure 5-18 Breakeven point for judging an MOO based on labor cost

Sensitivity on the development of QC productivity

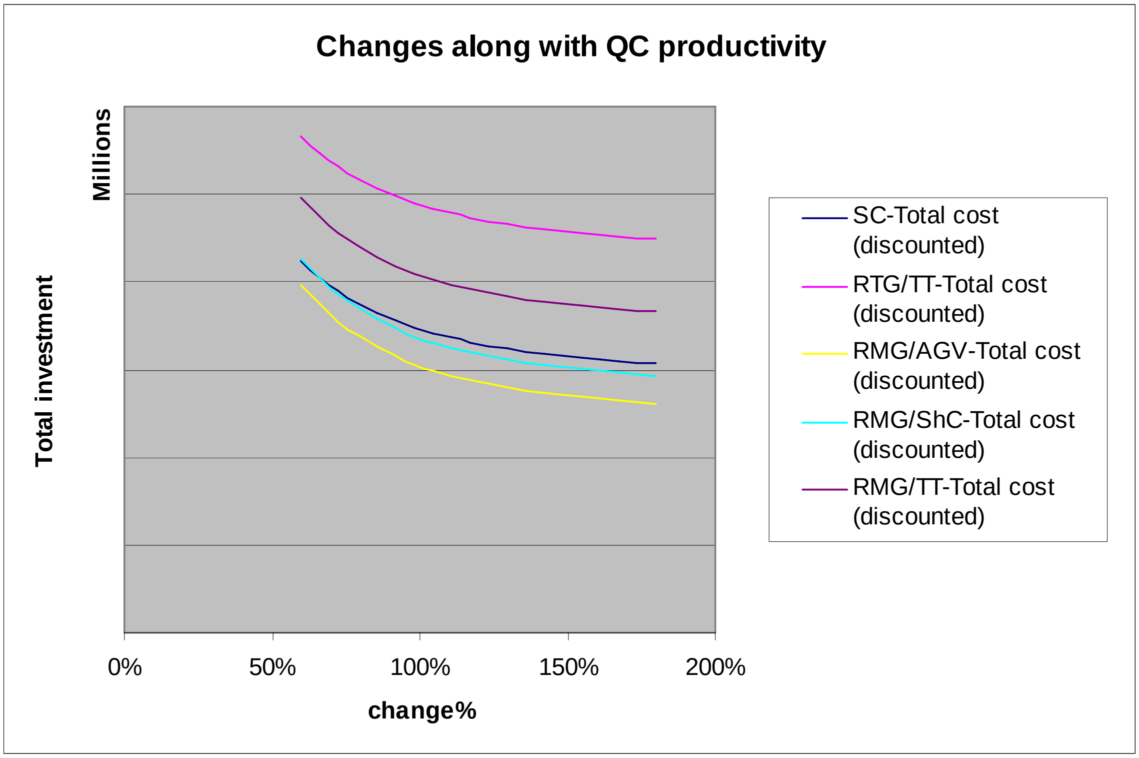

Figure 5-19 Sensitivity on the development of QC productivity

Figure 5-19 illustrates the dependency of the total cost on the development on quay crane productivity. The changes of QC productivity within its limits make the optimal choice of operation remain the automated operation.

The graphics showing the sensitivity on the development of other variable are present in appendix VI. There is no change of the choice of mode of operation observed by changing the value of those variables.

5.7 Conclusion and recommendation

The important variables which will affect the total cost of a project were identified, and it was examined how the uncertainty of those variables influences the choice in the sensitivity analysis. It was shown that the uncertainty on volume, annual volume growth rate, labor cost for blue collar and discount rate will affect the total cost a lot. However, the optimal choice of mode of operation is not sensitive to the changes of those variables; RMG/AGV is always to the best choice in each of the tests.

However, this sensitivity analysis has been done based on the assumption that all the variables influencing the total cost are independent. When testing the influence of the changes on one variable, it was assumed that all the other variable keep their default value. That is not always the truth; there might be correlations among variables. For example, the actual volume a terminal can handle is related to the value of dwell time (Saanen, 2004). Inflation of price also has a close correlation with labor cost (see Akerlof and Yellen, 1985). Those correlations could cause a different result of sensitivity analysis.

Therefore, the recommendation is that the company should put some effort on researching those important variables. As shown also in this sensitivity analysis, social economical indicators such as labor cost, discount rate have a big impact on the cost calculation. Possibly, it is necessary to build a business intelligence system to store historical data in their business and also to inspect the changes of world economy. That can both be beneficial to estimating the future value of variables and to investigating the correlations among variables.

6 Case studies on MV II project

In this chapter, a case study will be presented about using the Business Model in the MV II project. The background of MV II including the objective, the people involved, and the reason why BM is needed in this project is described in section 6.1. Section 6.2 presents the specification and the results from the BM. The results from the simulation model will be presented and compared with the results from the BM in section 6.3. Conclusion will be given in section 6.4.

6.1 Background for the Maasvlakte II project

6.1.1 *Introduction of the terminal at Maasvlakte II*

Maasvlakte II is the new 1.000 hectare Extension project of the port of Rotterdam on land reclaimed from the North Sea for which APM Terminals has secured a long term concession for a new terminal with 3.3 km of quay wall and 167 hectare of land (see Figure 6-1).

Figure 6-1 Prospect of Maasvlakte II (Source: APMT interanet)

Figure 6-1 show the prospect of the Maasvlakte II area, where the APMT concession is circled in red. After the concession was secured by APMT, a group called “Maasvlakte II team” was founded to deal with the business for the new terminal at Maasvlakte II. APMT is aiming to achieve the maximum throughput capacity of the Maasvlakte II container terminal in the most cost effective, productive and customer responsive way. In the context of Rotterdam, this means that the terminal will be automated to a certain extent, as the labor costs are high.

6.1.2 Comparing two different terminal designs

APMT would like to use innovative concepts in the development of this terminal. A consultancy company, which is specialized in making terminal simulation, is hired by APMT to investigate and access several alternative terminal configurations, specific the most innovative alternative, which was a new mode of operation. The consultancy company has been involved in many similar projects regarding the design of automated terminals equipped with RMG, cooperating with APMT and with other terminal operators. Therefore, the results provide by the consultancy company are highly trusted by APMT.

Recently, in order to make an in- house comparison of the implementation of two modes of operation, the new Business Model was selected by the Maasvlakte II team as the tool to make the comparison. The aim, the people involved and the tools used in that in-house comparison project are as follows:

- Objective: compare the implementation of two modes of operation by means of judging the financial indicators, such as NPV, IRR and payback time.
- People: BDV manager, operational manager, Project manager of Maasvlakte II. People who was supporting the use of the Business Model.
- Tools: Business Model and Financial Model.

The project manager and the operational manager are responsible for providing the input data of the Business Model. The BDV manager is responsible for guiding the use of the

Financial Model and analyzing the result from the Financial Model. The exact link between the Business Model and the Financial Model for this project is shown in Figure 6-2.

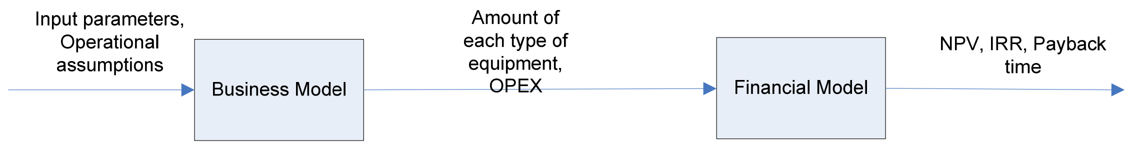

Figure 6-2 Link of Business Model and Financial Model

The expected outputs are the OPEX and the number of each type of equipment during the implementation for those two modes of operation. The number of each type of equipment is the most important output which is also calculated in the simulation model by the consultancy company. A comparison between the Business Model and the simulation model can therefore be made.

6.2 Comparing the results from the Business Model and the consultancy company's simulation model

The operational assumptions / inputs are provided by the project manager and the operational manager from the Maasvlakte II team. Those assumption / inputs include the following components:

- Volume specification: throughput, peak factor, TEU factor.
- Cargo flow: % full/reefer/MT, transshipment percentage.
- Stack configuration: number of housekeeping (movers/hr), origin/destination of containers, stacking range definitions, dwell time.
- Landside operations: productivity of rail crane / AGV.
- Terminal configuration; length of quay wall, length of stack.
- Equipment specifications: QC, RMG, AGV, Barge crane, TT and chassis.

As mentioned above, the required amount of each type of equipment is the most important output, which will be input to the Financial Model to judge the profitability of the two modes of operation.

The results for the fully built terminal from both models are quite close (see Figure 6-3), and the results from the Business Model were approved by the project manager and operational manager of the Maasvlakte II team.

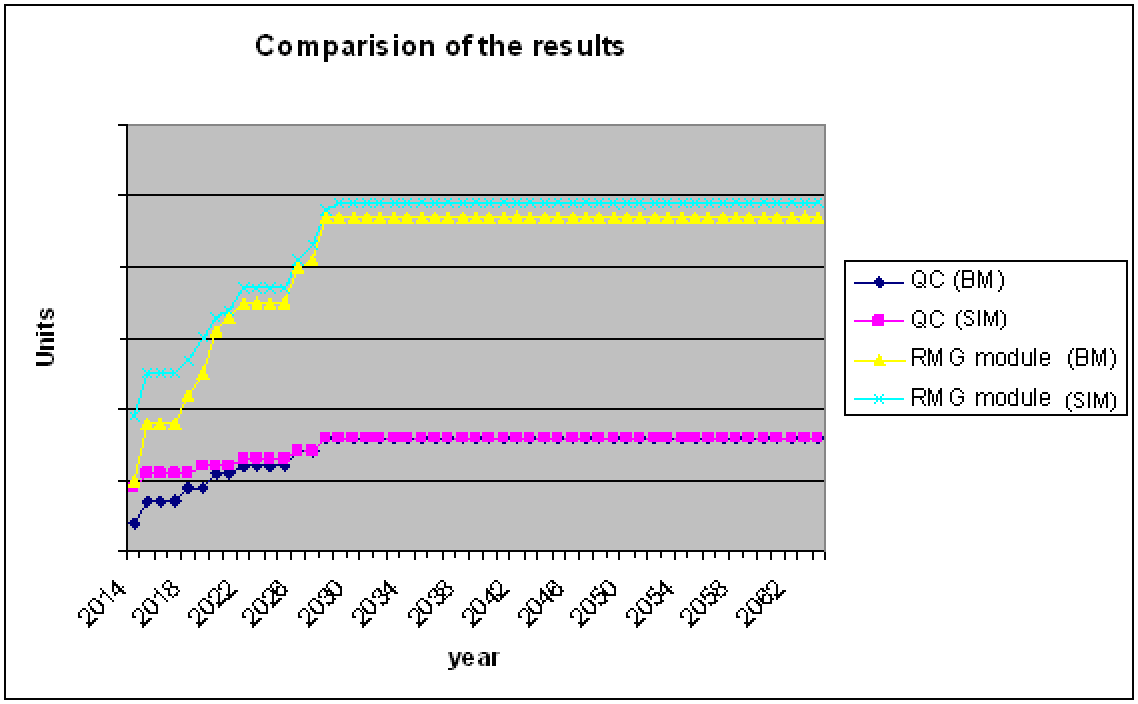

Figure 6-3 Comparison of the results from the BM and the consultancy company (All the numbers here are for example only; they do not represent the actual figures)

It is shown the terminal's build-up in the consultancy company's study (SIM) is faster than in the Business Model. The amount of quay cranes required increases slowly from the starting phase to the fully built up phase, whereas the throughput is almost doubled. The slight difference between the two models has been studied. That is because the consultancy company's study also takes dynamic situation into account, e.g. vessel arrival pattern and the waiting time for transportation. The biggest reason that causes the required amount of quay cranes from the consultancy company's study to be higher than that from the Business Model is that the consultancy company applied the service level of deep-sea vessels as a criterion in the simulation model. That criterion is the percentage of cases where the waiting time of the deep-sea vessel is more than 8 hours should not greater than 1%. It order to fulfill this criteria, more cranes have to be added to reduce the service time especially in the peak hour. That makes the required number of quay crane higher in the consultancy company's model than in the Business Model, since Business Model is based on a static planning. However, the peak factor is also taken into account in the calculation of the Business Model, but it is just an estimation based on the most likely case. Often, fluctuation of the arrival pattern is relatively large in the starting stage and it opts for smooth in the fully developed stage. That is why the results for the fully built terminal are quite closed in both models.

6.3 Conclusion

From this case study, the conclusion can be made in two perspectives: the accuracy and the usability of the Business Model.

Accuracy

The results calculated by the Business Model have been compared to the results of the consultancy company's simulation model, which is trusted by APMT. The result of the comparison shows that the Business Model's calculation is accurate in calculating the required amount of equipment for a terminal. That is also the basis for comparing each mode of operation in the Business Model. Given the fact that homogeneous monetary assumptions are used to calculate the cost for each mode of operation, as long as the number of required equipment is calculated accurately, the comparison of the cost for different modes of operation should also be accurate. In that sense, the comparison of mode of operation by the Business Model is accurate.

Usability

The Business Model was working well during the case study. It provides the results that users were looking for.

Iterations of recalculating the result between the Business Model and Financial Model have been observed in most of the business cases in APMT. Normally, when the result from the Business Model has been recalculated, the BDV manager has to type the result manually. That is not convenient to both the BDV manager and the person who uses the model, while time is precious for both of them. In this case study a special output sheet is made in the Business Model, which contains all the information required by the Financial Model. Although the interactions happened during this case study, the time used for that is minimized by the standardized output sheet. Copying the results of the terminal buildup from the Business Model and pasting them to the Financial Model is a way of saving time and keeping the integrity of data.

Besides that, the Business Model was calculated much quicker than the simulation model which needed almost one week to update the result when the assumption changed in this case study.

7 Evaluation of the Business Model

In this chapter we describe the evaluation procedures carried out on the reengineered Business Model. The evaluation of the Business Model was carried out using expert interviews with the purpose of evaluating the improvements on the Business Model as stated in the research question.

7.1 Design of evaluation

7.1.1 The purpose of evaluation

The implementations of the improvements on the previous Business Model were presented in chapter 4 and chapter 5. Now, I will discuss the evaluation that was carried out based on the aspects of accuracy and usability of the Business Model. The aim of carrying out this evaluation is to address the last research question: "*Are the usability and accuracy of the Business Model improved, and to what extent are they improved?*"

7.1.2 Evaluation method

Expert interviews were considered as the preferred research instrument to evaluate the improvement to the Business Model. This research instrument was chosen because that there are not so many automated terminals operated by APMT. That makes it impossible to compare the results from both the old model and the new model with the statistical results derived from real terminal operation. Therefore, experts having both modeling and terminal operational experience were considered to be the best option to evaluate this project. On the other hand, whether the usability of the new model is improved compared with the old one is subjected to the users' opinion. Interviewing the user is the only way to do so.

The objective of the expert interview was to evaluate whether the accuracy and the usability of the Business Model improved in this research. The focus of the interviews was on calculations performed by the model and the way of communicating with the user.

7.1.3 Structure of the expert interviews

Selection of the experts

The experts have been chosen based on the following three criteria:

- has expertise in terminal operation,
- has rich experience on modeling complex systems,
- is familiar with the previous version of Business Model.

There are not many experts being suitable to interview according to the above mentioned criteria or the difficulties of arranging a suitable time. On the other hand, due to confidentiality, it is not allowed to represent this model to external experts. Therefore only three experts have been selected to interview:

- The owner and the developer of the model;
- A project manager in the head office
- A project manager in Maasvlakte II team who is familiar with the Business Model and also used the model in the business case.

They are selected because the owner of the model knows every detail of the model; he is expected to give comments on the changes of the model from high level observation to detailed calculations; the project manager in the head office also knows both the previous model and the new model very well. He has been selected also because that he is independent on the development of the Business Model. Therefore his comments would be expected more objective; the reasons of choosing the project manager are not only that he is familiar with the model but also he can provide the comments from a user's perspective.

Since the numbers of interviewee are limited, it is not suitable to make the statistical analysis on the interview results. Instead, the questions of interviews will focus on the in-depth reason of giving a certain statement by the expert, such as "*why*" questions.

Focus of expert interview

As the objective of the expert interview is judging the improvement on the Business Model, the questions to the expert will focus on the following:

- if the accuracy and usability has been improved,

- which calculation and what aspects of usability has been improved,
- why the expert think the accuracy and usability has been improved,
- if the expert has any suggestion about further improve the accuracy and usability of the Business Model.

7.2 Findings from expert interview

In this section, the result from the expert interviews will be presented in two categories which are aiming to address the questions on accuracy and on usability. Minutes of expert interviews to are presented in appendix VII. Since views of different experts did not differ a lot, results have been combined.

7.2.1 Regarding the accuracy

Within the concept of accuracy, two aspects can be distinguished:

1) accuracy of the comparison between modes of operation to determine the optimal one
2) accuracy of the calculation for each mode of operation

In the first perspective, the improvement of the accuracy of the Business Model is not obvious, that is because the following reason:
The previous model is created as a tool to compare modes of operation. It emphasized on the consistency in calculating the result for each mode of operation, and was considered successful in doing that. Therefore not much improvement of the accuracy of the comparison was needed.

In the second perspective, the accuracy of the Business Model was improved. The following calculations were all improved:

- the calculation on the M&R time,
- the calculation on equipment's productivity,
- the calculation on the required amount of equipment,
- the calculation on the terminal inventory,

- the calculation on terminal KPIs.

As evidence for those improvements, it should be noted that according to the expert the previous version of the Business Model is used mainly for comparing mode of operation, and now it can be used as a tool to calculate the exact number of required equipment during the planning.

It was also mentioned by the expert that even though the accuracy of the comparison is not improved a lot, the improvement of the accuracy on calculating for each mode of operation will increase the trust of the user in the model. That is valuable for both the user and the developer.

7.2.2 Regarding the usability

According to the expert's opinion, there are both pros and cons to the model's usability.

Pros:

The improved interface and graphs increase the usability of the model. Nice interfaces allow the user to configure the model easily and quickly. Many added graphs provide the user with lots of insight to understand the results from the model.

Cons:

In the expert's viewpoint, the new functionality of sensitivity analysis does add value to the expert, but not to the normal user who does not have a mathematical background. To use it effectively, the company has to put lots of effort in training the normal user.

8 Conclusions and Recommendations

In this chapter, the answers regarding the research (sub) questions will be addressed and two categories of recommendations will be presented.

8.1 Findings of this research

In this section, we present the research findings by discussing and answering our research questions. The objective of this research is trying to improve an existing model to provide better support to the user by adding new functionality and increasing the accuracy of the calculations in the model. In order to improve the Business Model, I formulated several research questions in chapter two. I will discuss the answer of each research question below.

The first research question was formulated as: *How is a container terminal operated? Which modes of operation are available for container terminal operation?* This research question was intended to help me get a clear idea of container terminal operation.

This question has been address in chapter 3, in which a container terminal's structure, process and functions and terminal's key performance indicators were presented in sufficient detail for the purpose: to provide the necessary background for understanding and extending the existing Business Model. Chapter 3 also presented the various modes of operation in contemporary marine container terminals, among which SC, RTG/TT, RMG/AGV and RMG/ShC are mainly focused in the Business Model.

As stated at the beginning of this report, this research intended to improve the existing model. To this end, a good understanding of the previous model is needed. Therefore, I formulated the second research question as: *What is the prototype of Business Model? How does the BM function? What kind elements/ parameters should be taken into account in the BM? What improvement can be made to its calculation?*

The answer of this question was elaborated in chapter 4. In that chapter, the model's boundary, structure and input / output parameters were explained. The desired improvements beyond the old model were identified from a stakeholder analysis and a requirement analysis. Finally, the implementations of those improvements were presented in the last section of chapter 4.

Given the fact that the input parameters are not 100% accurate, there are some uncertainties on the estimation of their values. People would like know what will be the optimal mode of operation if the value of a parameter changes. In order to answer this question, I formulated the third research question as: *How sensitive of the total cost of each mode of operation to its input parameters?*

The functionality of sensitivity analysis to the previous model has been added in chapter 5. A study of the sensitivity of the choice of mode of operation with respect to variable set-up of the Business Model has been demonstrated as well in that chapter. A list of uncertain and important parameters, which the result of the Business Model is sensitive to, were identified by using Tornado diagrams and Spiderplots. Finally, refining those parameters was presented as a recommendation.

In some literature regarding terminal operation, labor cost, especially blue-collar cost, was found to be the main component in the total cost. People are quite interested in knowing whether blue-collar labor cost can be an indicator of choosing a certain mode of operation. Therefore, the fourth research question was formulated as: *what level of blue-collar labor costs could justify a specific Mode of Operation?*

The answer was present in chapter 5 as well. It was identified by finding the breakeven point between the automated mode of operation and the human-based mode of operation as a function of the blue-collar labor cost.

Finally, whether this research reached the expected goals was judged by answering the last research question, which was formulated as: *Are the usability and accuracy of the Business Model improved, and to what extent they are improved?* To answer this question, two methods were employed in this research. One was case study, which was aiming to validate the accuracy of the new model. The other one was expert interviews, which was used to evaluate the improvement compared to the previous model.

A case study had been done in this research and was presented in chapter 6. The accuracy of the calculation in the Business Model has been validated by comparing with a highly trusted simulation model. On the other hand, the usability of the model has been judged by observing the use of the Business Model in a real business case. The findings of the cast study show that the Business Model is accurate in calculating the required amount of each type of equipment and in comparing modes of operations as well. It was also shown that the Business Model could be used very well in evaluating the business case within APMT.

Last, the accuracy and the usability of the new Business Model were compared to the previous version by means of an expert interview (see also chapter 7). From this experts' assessment it was found that the accuracy of the calculations performed by the model was improved. However, according to the experts, the accuracy of the comparison between different modes of operation was not improved too much; it was already considered accurate enough before this research started. This outcome is a bit surprising, because one would expect that an increase of the quality of the computations would affect the accuracy of the comparison. More research is needed.

According to the expert, the usability is further improved by adding more graphical views and by improving the user interface, while the new functionality of sensitivity analysis does not yet add value to the usability of the model and it is still considered too complex for normal users without help of an expert. This finding also deserves further attention, since all that is needed to use the sensitivity functionality, is to understand the parameter ranges and to be able to interpret the graphs. In addition to that, I think that sensitivity analysis is really useful to improve the interaction between the Business Model and the Financial Model. For example, if the BDV people know the sensitivity of the comparison to each variable, a small change on the insensitive variables will not influence the choice of the mode of operation. In that case, it is not necessary to run the Business Model again. However, the reasoning behind the expert's opinions was not researched. That could be a question for future research.

8.2 Limitations

There are two limitations of the Business Model that have been found during this research:

1) Dynamic factors are not taken into account in the Business Model

Terminal operation as a complex material handling system is a very dynamic process. Whereas the static planning the Business Model is doing may not be capable to deal with the dynamic situation properly. In most cases, static planning may underestimate the influence of dynamic changes in the real terminal operation. For example, a delay of the arrival of a big vessel may cause longer queuing for other vessels which are waiting for the loading and unloading by quay cranes. In order to keep the same service level, more quay crane should be added to the terminal.

2) Revenue is not taken into account in the Business Model

It is observed that lots of the business cases are judged by considering financial indicators, such as NPV, IRR and payback time. Often, those indicators are highly interesting for the stockholder. Somehow, whether an investment will succeed is determined by whether those indicators perform well. Only considering the cost of each mode of operation might lose the insight that could be obtained from the revenue side.

8.3 Recommendations

The recommendation is made to APMT to focus on increasing both the accuracy and the usability of the model.

For more accuracy

① Establish a business intelligence system

The advantages have been demonstrated in chapter 5.

② Use a dynamic simulation model

Simulation is seen as the best way to gain insight in the real process. It has been successfully used in the study of marine container terminals. Even though, it is sometimes time consuming and costly, it does add value by providing much more accurate results than static planning does. On the other hand, simulation can provide a distribution of the performance of the observed process, which can also be used as the input of the static planning tool. By doing so, the risk of implementing a project can be addressed easily.

For more usability

① Provide more performance indicators taking from a broader perspective

Obviously, a decision of choosing a mode of operation can not be made by only considering the financial or operational performance. Making such a decision is a complex procedure among multiple actors using different criteria. Even though some performance aspects can not be fully quantified such as legal considerations and safety issues, the more considerations can be added to the model, the clearer the comparison of each mode of operation can be made.

② Link the Business Model with a Financial Model

Iterations between the Business Model and the Financial Model have been observed during the case study. Any changes in either model will cause the rerunning of the other model. That is annoying by the users of both models. On the other hand, the results calculated by the Business Model which will be manually transferred to the Financial Model, so the integrity of the data can not be secured. Therefore, I suggest linking both models, but not simply linked as one model. By consulting the expert who has been involved in lots of business cases in APMT, it is found that most of the BDV managers in AMPT are not an expert in the operational aspect. Thus the calculation results regarding the operational indicators have to be examined first by the operational expert. Simply linking the models will lose the power of the dual-checking. The proposed linked is shown in Figure 8-1. BDV people provide a standardized input sheet including the information the Business Model will use for its calculation, such modal splits, projected volume, peak factor etc. There will be two output sheets provided by the Business Model. One is the standardized output sheet which includes the information that the Financial Model needs, such as the amount of required equipment and the OPEX. The other one is the assumption which is used during the calculation in the Business Model. Then BDV people should check if the additional assumptions are consistent with the ones they will use in Financial Model. If yes, then the result from the Business Model should be copied to the Financial Model directly without any revision. If not, then the validity of those assumptions should be double checked and the second round started until all the assumptions are valid.

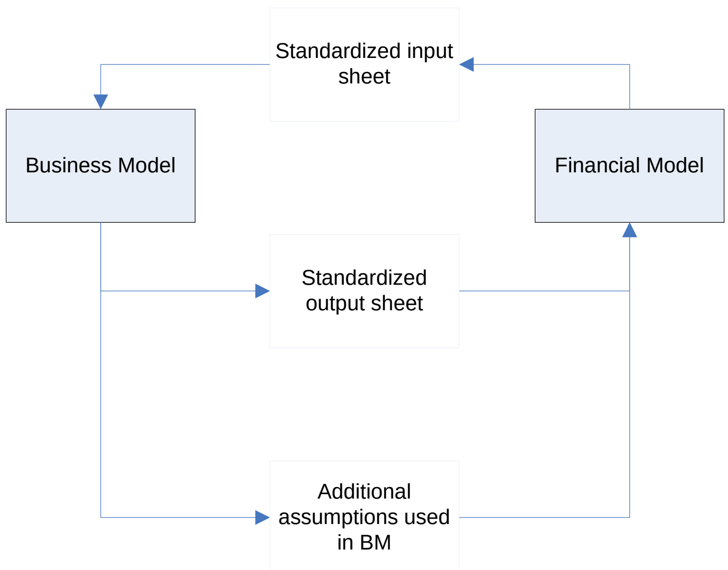

Figure 8-1 Proposed decision loop between Business Model and Financial Model

8.4 Reflection

Within this research, a new version of the Business Model has been developed and launched in APMT. It was the most challenging project I have ever experienced. In addition to analyzing the problem and thinking of new ideas, a challenging task was implementing those ideas in a spreadsheet, on which I spent lots of time during this project. For instance, in order to make the calculation and graphical view automatic and dynamic, some programming techniques and algorithms were used, which are really time-consuming. Writing the user manual is also part of this project, which is quite time-consuming as well, but they were too detailed to describe in the thesis.

Apart from the technical difficulties, the organizational difficulties were also challenging me a lot during the entire project. It is a fact that a university always requires theoretical and scientific achievements, while company requires practical achievements at the end. How to properly balance the time spent on fulfilling those two requirements was a difficult question for me during the project period. Also, it is common that there are more or less some organizational issues in every big company. Usually, those problems can not be solved by only using the purely scientific approach.

However, I would like to say it was a really valuable and gainful project, since I believe that no pains, no gains. From solving all the difficulties which I faced during this project, I really learnt a lot, such as how to perform well in a multinational environment, how to deal with the task with a tight schedule for delivery. Even though most of those acquirements can not be reflected on the thesis, it is indeed important for my future.

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List of appendices

Note: All the numbers used in appendices are for example only; they do not represent the actual figures.

Appendix I: Relationship between input and output sheet in Business Model

Not included in the public version.

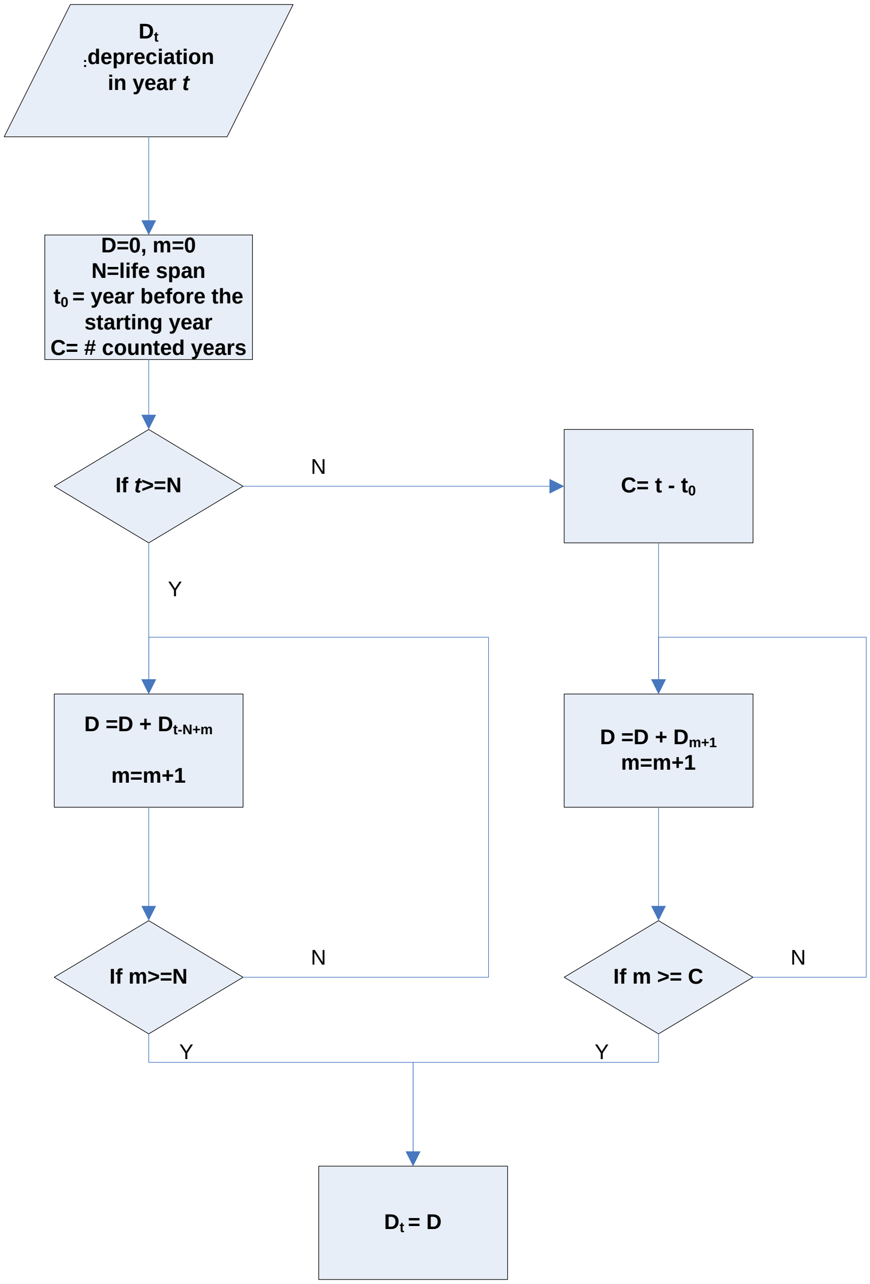
Appendix II: Snapshots of the Business Model

Not included in the public version.

Appendix III: Implementation of depreciation method in the BM

As it is shown in the test model, fist cost of each transaction will be equally divided by the life span of the given equipment. And its depreciation will spread in the following numbers of years, where the number should be exactly equal to the life span of equipment. It will be an iterative procedure of spreading the depreciation for each happening first cost. As long as the fiscal year reaches to the year when the first replacement of equipments should happen, the responsible depreciation cost of that year will be calculated by summing up all the N depreciation cost which is initiated in the previous years, where N exactly equal to the life span of equipments. So do the following fiscal years. For the years prior to the first replacement, it only needs to sum up the deprecation costs which happened from the beginning of the project. The calculating algorithm is shown in the following figure. By implementing that in BM, it is needed to first exam if the time span between the current year and the starting year reaches the life span of the using equipment. If the answer is yes, we call the bunch of numbers which represent the number newly brought equipment from the current year to the Nth-year before the current one. And then multiply the called numbers with the purchasing price in the corresponding year respectively, and subtract the result of multiplying the called numbers with the Salvage value in the corresponding year respectively, and finally divide the lift span.

When the current year has not reached the first year with replacement, we should use the same way to calculate. The only difference is that the range of data we called is decided by the series number of the current year. For instance, if it is the third year, we call three years of number from beginning.



Depreciation algorithm

Appendix IV: Tornado diagram for each MOO

Not included in the public version.

Appendix V: Spiderplots for each MOO

Not included in the public version.

Appendix VI: Sensitivity of the choice of MOO on the development of other variables

Not included in the public version.

Appendix VII: Minutes of expert interviews

Not included in the public version.