An Integrated Framework for Optimisation of Oil Field Production Area

Alsanosi Ibrahim E. Omer

A thesis submitted in partial fulfilment of the requirements of

Sheffield Hallam University

for the degree of Doctor of Philosophy

June 2009

Preface

This thesis is presented as part of the requirements for the award of the degree of Doctor of Philosophy from Sheffield Hallam University in UK. The reports for research and works carried out by the author were supervised by Professor Sameh Saad from Faculty of Arts, Computing, Engineering and Sciences at Sheffield Hallam University between March 2005 and June 2009.

Alsanosi Omer

June 2009

Acknowledgements

I would like to show my profound gratitude to my supervisor Prof. Sameh Saad, my colleagues King Hua Lau and Aririguzo Julian, and those who were not mentioned here for the extensively invaluable advice and help from them. Thanks to them for providing the good working environment; I learnt a lot from their experiences.

Prof. Sameh Saad provided the opportunity by offering this project to me. Much constructive and critical advice was given and inspired my thought in this thesis. He offered a lot of his valuable time and effort whenever I faced any difficulty in carrying out the work and directed me towards the right path whenever I strained from the point.

I would like to thank my family for their encouragement and understanding and my brothers and sisters for their support. They were there whenever I was frustrated, comforted me, and motivated me. I dedicate this thesis to them.

Abstract

Crude oil separation processes involve many high-profile control-systems and equipment costing many millions of pounds including the maintenance of, and resources for, all facilities. Mistakes made in decision-making will have serious consequences. This makes the management of decision-making in oil-production more challenging as to how the productivity as well as the profitability can be increased. This project focuses on developing an integrated framework to optimise crude oil production area which includes oil wells area such as crude oil transportation and production area (crude oil separators). Mathematical programming and simulation modelling are used to investigate these issues and examine how they could be improved. The crude oil produced from different oil-wells of different capacities in different locations is of different quality. This crude oil is collected in a place called the manifold, then distributed to different separators. This environment is represented mathematically using linear programming which will help to improve the decision-making in crude oil-well selection. The nature of an oil-production system is categorised as a continuous environment and simulation models proposed in this work represent a step forward in modelling technique, as it is rare to find such types of models in the literature. The results from the simulation experiments are documented and presented graphically. This enabled the decision-making to be more effectively carried out through analysis. In addition, a full commentary of the proposed simulation model is provided to help practitioners and users in the ways of modelling such an environment using a systematic approach with animation. An integrated, user-friendly interface is developed for variable set-ups, enabling different experiments to be carried out and factors to be explored more easily.

Publication from the Thesis

Saad, S, Lau, K.H, and Omer, A, (2009), "Design and Analysis of Oil Production Area _ A Simulation Approach", 23rd European Conference on Modelling and Simulation ECMS 2009, Madrid, Spain, 09-12 June 2009.

Table of Contents

Preface i

Acknowledgements ii

Abstract iii

Publication from the thesis iv

Table of Contents v

List of Tables x

List of Figures xii

Nomenclature............. xvii

Chapter One........ Introduction and Company Background 1

1.1 Introduction to the Project and Problem-definition 1

1.2 Company Background...3

1.3 Aims and Objectives of the Thesis...5

1.4 The Thesis's Structure...6

Chapter Two.......... Literature Review 8

2.1 Introduction...8

2.2 Crude Oil Transportation 8

2.3 Crude Oil Transportation Methods 9

2.4 The Background to Oil Production 10

2.4.1 What is Crude Oil? 10

2.4.2The Crude Oil Separation Process 11

2.5 Related Literature...16

2.6 Conclusion....25

Chapter Three.....Research Methodology and Proposed Framework...........27

3.1 Introduction....27

3.2 Mathematical Programming Histories....27

3.3 Transportation Model....29

3.3.1 The Problem with Mathematical Solutions in Crude Oil Production....30

3.4 Methods Available for Research in General....30

3.4.1 Mathematical Modelling....30

3.4.2 Heuristic Modelling....32

3.4.2.1 The Disadvantage of Mathematical Modelling and Heuristic Modelling....32

3.4.3 What is a Modelling?....33

3.4.4 Computer Simulation Modelling....34

3.4.4.1 The Advantages of Computer Simulation....35

3.5 The Computer Simulation Method....37

3.5.1 The Purpose of Simulation....38

3.5.2 Types of Simulation....39

3.5.3 Issues Related To Simulation and When Simulation Is Used?....40

3.5.4 The Simulation Process....41

3.5.5 Simulation Tools Available....43

3.6. ARENA Simulation Tool....45

3.6.1 Arenas Framework....46

3.7 The Proposed Framework for the Optimisation of Oilfield Production Area.....49

3.8 Conclusion..52

Chapter Four........Oil-Wells Optimisation Model..53

4.1 Introduction..53

4.2 Model Presentation..53

4.3 Proposed Mathematical Optimisation Model..54

4.4 Modelling the Bu-Attifel oilfield..56

4.5 Implementation of the Proposed Mathematical Model Using Lingo/ Lindo. 64

4.5.1 In the case of supply equals the demand..65

4.5.2 The Supply is Greater Than the demand..66

4.5.3The Supply is less than Demand..67

4.5.4 Demand grater than supply (Dummy solution)................................68

4.5.5 The Supply Greater than Demand (Dummy solution)........................ .69

4.6 Results Analysis and Discussion..70

4.6.1 Introduction of Dummy Supply and Demand....................................72

4.7 Conclusion..73

Chapter Five... ......Modelling and Analysis of the Oil Separation Area........75

5.1 Introduction..75

5.2 Conceptual Model..75

5.2.1 Objectives of the Simulation Modelling..76

5.2.2 Process Flowcharts..76

5.3 Data Collection and Assumptions..81

5.3.1 Input and Experimental Factors..81

5.3.2 Outputs..82

5.3.3 Assumptions and Model Simplification..82

5.4 Model Building and Descriptions 88

5.4.1 Tank Modelling..90

5.4.2 Separation Process from Manifold to Stage 1 (S1) Separators (SP)...........91

5.4.3 Separation Process from Stage 1 Separators to Stage 2 Separators 97

5.4.4 Separation Process through Stage 2, 3 and 4.......................................99

5.4.5 Separation Process from Stage 4 Separators to Stage 5 Storage Tanks.....102

5.4.6 Separation Process from Stage 5 Separators to the setting up the Delivery...105

5.5 Verification and Validation..108

5.5.1 Methods for Verification...108

5.5.2 Verification and Validation Carried Out in the Model..............................110

5.6 Conclusion..113

Chapter Six............ Experiments and Results..114

6.1 Introduction...114

6.2 Experiments and results..115

6.3 Conclusion..124

Chapter Seven................ Results Analysis and Discussions..........................125

7.1 Introduction...125

7.2 Input- rate and Number of Production- line Versus Quality of Crude Oil.........126

7.3 Input- rate and Number of Production- lines Versus SP Capacity....................132

7.4 Results Analysis 139

7.4.1 Choosing a Statistical Test 139

7.4.2 ANOVA (analysis of variance)..139

7.5 Conclusion..150

Chapter Eight...... Conclusions, Contribution to Knowledge, Limitation and Further Works..152

8.1 Conclusion...152

8.2 Contribution to Knowledge...155

8.3 Limitation and Further Works...156

References...158

Appendix A .... Oil Wells Optimisation model...169

Appendix B...........ARENA Model Logic Diagrams..198

Appendix C...........VBA Code...209

Appendix D...........Picture of Manifold, Separators and Tanks.......................251

List of Tables

Table 2.1 Top World Oil Producers..14

Table 2.2 Top World Oil Consumers..15

Table 4.1 Bu-Attifel Oilfield oil-wells information..58

Table 5.1 Data Provided...84

Table 5 2 Component list for model..85

Table 5.3 Calculation of the oil output-rate at each stage....................................86

Table 5.4 Calculation of the gas, oil and water Ratio..88

Table 5.5 Flow Process modules used...89

Table 5.6 Basic Process modules used..89

Table 5.7 Advanced Process module used...89

Table 5.8 Block used..89

Table 6.1 Symbols and Values..115

Table 6.2 Set 1 Different Production-line and water-content with U1 input-rate...116

Table 6.3 Set 2 Different Production-line and water-content with U2 input-rate...117

Table 6.4 Set 3 Different Production-line and water-content with U3 input-rate...118

Table 6.5 Set 4 Different Production-line and water-content with U4 input-rate...119

Table 6.6 (a) Experiment for Changing Input- rate with fixed SP capacity.........120

Table 6.6 (b) Experiment for Changing Input-rate with fixed SP capacity..........121

Table 6.7 Set 5 Different Production-line and SP capacity with U1 input-rate.......122

Table 6.8 Set 6 Different Production-line and SP capacity with U2 input-rate.......123

Table 6.9 Set 7 Different Production-line and SP capacity with U3 input-rate.......123

Table 6.10 Set 8 Different Production-line and SP capacity with U4 input-rate.....124

Table 7.1 Output of Univariate Analysis of Variance...142

Table 7.2 Output of Univariate Analysis of Variance..149

List of Figures

Figure 2.1 Example of crude oil wells distribution..9

Figure 2.2 (a) Horizontal Separator; (b) Vertical Separator............................12

Figure 2.3 Horizontal three-phase separator schematic.................................12

Figure 3.1 Framework in Simulation Study..43

Figure 3.2 Important Criteria for the Proposed Model..................................45

Figure 3.3 Arena Window for the Simple Processing System........................48

Figure 3.4 The Proposed Integrated Framework...51

Figure 5.1: Process Flow-Chart of Crude Oil Separation................................79

Figure 5.2 Crude Oil Separation-Process Layout Diagram..............................80

Figure 5.3 ARENA Flow-chart of Manifold Refill..90

Figure 5.4 Flow-chart of Crude Oil Separation from Manifold to Stage 1 Separators..95-96

Figure 5.5 Flow-chart for Separation from Stage 1 to Stage 2........................98

Figure 5.6 Flow-chart of Separation from Stage 2 to Stage 3..........................100

Figure 5.7 Flow-chart of Separation from Stage 3 to Stage 4..........................101

Figure 5.8 ARENA Flow-chart of Separation from Stage 4 to Stage 5..........104

Figure 5.9 Flow-chart of Oil Transfer from Storage Tank (Line 1&2)...........106

Figure 5.10 Flow-chart of Oil Transfer from Storage Tank (Line 3&4).........107

Figure 5.11 Basic Model-building and Testing..111

Figure 7.1 Oil Out-put against Water Content with four Production-lines with Input-rate U1..128

Figure 7.2 Out-put against Water Content with four Production-lines with Input- rate U2..129

Figure 7.3 Out-put against Water Content with four Production-lines with Input-rate U3..129

Figure 7.4 Output against Water Content with four production-lines with Input-rate U4..130

Figure 7.5 Output against Water Content with combining Figure 7.1 to Figure 7.4..131

Figure 7.6 Oil output with different Input-rate..133

Figure 7.7 SP Utilisation...133

Figure 7.8 Output against SP Capacity with four Production-lines with Input- rate U1..135

Figure 7.9 Output against SP Capacity with four Production-lines with Input-rate U2..136

Figure 7.10 Output against SP Capacity with four Production-lines with Input-rate U3..136

Figure 7.11 Output against SP Capacity with four Production-lines with Input-rate U4..137

Figure 7.12 Output against SP Capacity with combining Figure 7.8 to Figure 7.11..138

Figure 7.13 Snap-shoot of the SPSS Data-view Sheet....................................141

Figure 7.14 Snap-shoot of the SPSS Variable-view Sheet...............................141

Figure 7.15 Estimated Marginal Means of Total oil output

at Water-content - 0.75..143

Figure 7.16 Estimated Marginal Means of Total oil output

at Water-content - 0.50..144

Figure 7.17 Estimated Marginal Means of Total oil output

at Water-content - 0.25..144

Figure 7.18 Estimated Marginal Means of Total oil output

at Water-content 0.0...145

Figure 7.19 Estimated Marginal Means of Total oil output

at Water-content 0.25...145

Figure 7.20 Estimated Marginal Means of Total oil output

at Water content 0.50..146

Figure 7.21 Estimated Marginal Means of Total oil output

at Water-content 0.75...146

Figure 7.22 Snap-shoot of the SPSS Data-view Sheet......................................147

Figure 7.23 Snap-shoot of the SPSS Variable-view Sheet.................................147

Figure 7.24 Estimated Means of Oil output at Different Capacity, Input-rate and

Number of lines...150

Appendix A..............Oil-wells Optimisation Model..................................169

Figure 1 Lingo Output when Supply Equal the Demand....................................170

Figure 2 Lingo Output when Supply Greater than the Demand.........................174

Figure 3 Lingo Output when Supply < Demand...178

Figure 4 Lingo Output when Demand > Supply (Dummy Solution)..................182

Figure 5 Lingo Output when Supply > Demand (Dummy Solution)..................186

Figure 6 Supply > Demand (Dummy Solution)..192

Appendix B..............ARENA Model Logic Diagrams.................................198

Figure 1 Model Logic of Crude Oil Separation from Manifold to Stage 1 Separators..199

Figure 2 Model Logic of Crude Oil Separation from Stage 1 to Stage 2 Separators..200

Figure 3 Model Logic of Crude Oil Separation from Stage 2 to Stage 3 Separators..201

Figure 4 Model Logic of Crude Oil Separation from Stage 3 to Stage 4 Separators..2002

Figure 5 Model Logic of Crude Oil Separation from Stage 4 Separators to Stage 5 Storage Tank..203

Figure 6 Model Logic of Oil Delivery from Stage 5 Oil Storage Tanks to Stage 6 Oil Centre..204

Figure 7 Model Logic of Manifold Refill...204

Figure 8 Tank Modules for Separators, Manifold and Storage Tanks.................205

Figure 9 Animation...206

Figure 10 Interface for Changing Separators Utilisation...................................207

Figure 11 Interface for Changing the Capacity of the Separators........................207

Figure12 Interface for Selecting the Production Line..208

Figure 13 Interface for Choosing the Water Contents in Crude Oil....................208

Appendix C...................VBA Coding...209

Appendix D..................Pictures...251

Figure 1 Manifold...252

Figure 2 API Oil - Water Separator...252

Figure 3 Horizontal Separators..253

Figure 4 Vertical Separators..253

Figure 5 Oil Storage Tank..254

Nomenclature

A	
A1	Number of production lines
A2	Number of production lines
A3	Number of production lines
A4	Number of production lines
ANN	Artificial Nerve Network
atm	Atmosphere, a unit of atmospheric pressure
B	
bbl	Barrels, unit for fluid
C	
C1	Capacity of separator
C2	Capacity of separator
C3	Capacity of separator
CFD	Computational Fluid Dynamic
C_i	Capacity of oil well *i*
C_t	Total oil wells capacity
D	
d_j	Demand at manifold (j)
DES	Distributed Energy System

dt	Change of time
dx	Change of distance
F	
f(x)	Derivative function
FORTRAN	Formula Translation, a high level programming language
FTP	Flowing tubing pressure
G	
gas ratio	Ratio of gas content in one barrel of crude oil
GPSS	General Purpose Simulation System, programming language for discrete event simulation
I	
i	Number of wells
J	
JAVA	A type of object oriented programming language
J	Number of Manifold
L	
LP	Linear Programming
Lingo & lindo	Software used to solve the mathematical model
M	
MILP	Mixed Integer Linear Programming

MIP	Mixed Integer Programming
MMscf	Million standard cubic feet, unit for gas
MRP	Material Requirements Planning
O	
oil ratio	Ratio of oil content in one barrel of crude oil
P	
PIMS	Process Industry Modelling System
R	
RPMS	Refinery and Petrochemical Modelling System
S	
S_{ij}	Distance from oil wells (i) to manifold (j)
S1	Stage 1
S2	Stage 2
S3	Stage 3
S4	Stage 4
S5	Stage 5
SIMAN	SIMulation ANalysis, manufacturing system simulation language
SIMSCRIPT	General-purpose programming language
SLAM	Discrete system modelling programming language
SP	Separator

ST1	Delivery tank 1
ST2	Delivery tank 2
ST3	Storage tank 1
ST4	Storage tank 2
SUM	Equation symbol used in Microsoft Excel representing summation
T	
TOC	Theory of Constraint
V	
VB	Visual Basic, programming language used for Windows application
VBA	Visual Basic for Application, common language for customising software applications, and extension of VB
VNS	Variable neighbourhood search
VSP	Vertical separator
W	
W1	Level of crude oil quality
W2	Level of crude oil quality
W3	Level of crude oil quality
W4	Level of crude oil quality
W5	Level of crude oil quality

W6	Level of crude oil quality
W7	Level of crude oil quality
water ratio	Ratio of water content in one barrel of crude oil
X	
x_{ij}	Amount of oil provided by well (i) to manifold (j)

Chapter 1

Introduction and Company Background

1.1 Introduction to the Project and Problem-definition

Crude oil is the important principal source of energy in the world, and is used as a resource in many areas of our daily life.

Many countries have tried to obtain this resource and have paid vast amounts of money to explore for oil. Whilst the exploration for oil is needed, it can be an expensive process, which includes the sourcing of the oil through to processing and finally delivery to the customer. Therefore, companies are working hard to optimise their project-operations.

Decreasing the oil-production cost begins with the exploration of the reservoir. This includes the different operations which are used to determine the location of the reservoir, and start-up costs of drilling the first oil-well which is a difficult and high-cost operation. Once the location and initial drilling are complete, the crude oil is produced from different oil-wells which are drilled in the reservoir and transferred to the surface.

In the oil field there are many problems related to the oil wells area and production area, for example enhanced of oil wells production these includes all the operations which should be carried out in the oil wells (e.g. water injection or gas injection) to improve the oil production. In other hand, there are other problems in the production area for example maintenance planning for separators, pumps, valves and tank.

One of the of the important problems involved is how to minimise the transportation-cost of the crude oil and at the same time guarantee a high-quality product which is requested by the customers, in order to fulfil particular demand over a particular period of time.

The oil-field contains many oil-wells with different capacities and quality of oil, and also with different distances from the oil-wells to the manifold.

The first problem this research will focus on is how to minimise the transportation-cost and to decide on the most suitable operational policy for the oil-well area.

The second problem considered in this thesis is the productivity and profitability of oil production area, where the crude oil surface-production operations are among the most dynamic chemical processes in the engineering field due to their complexity, high profile and high safety considerations. Whole refinery systems from crude oil to final consumable products are separated into several steps together with hundreds of complicated piping and control systems. The processes include 2-phase and 3-phase separation where all productivity at all stages is restricted by several factors if not effectively controlled. The whole production system is a continuous process over time including minor discrete events which will be discussed further in the literature review. Due to the dynamic process behaviours and increasingly fierce competition in industries, manufacturers always find it difficult to achieve high performance and thorough planning just by traditional design and analytical methods. Highly-automated and computer-controlled oil-production systems are not capable of achieving high performance and to integrate the complex systems. The risks and costs are too great and too high for implementation which is not completely tested and analysed for its effectiveness. Mismatches and unexpected factors are really worrying for most of the process and operations planning, and failures in the systems can cause enormous losses both in time and financially.

However, there is another challenge: to keep this equipment operating smoothly without a break. In this case maintaining this equipment is vital and the maintenance tasks, as well as the procedure that should be followed in case of unexpected break down, and how to cope with the subsequent incident should all be considered and planned carefully

1.2 Company Background

Eni is one of the prestigious energy companies operating in 70 countries over the world. Its head-quarters are located in Italy. Eni is generally involved in oil and gas, electricity generation and sale, petrochemicals, oilfield services, and the construction and engineering industries. Eni (Libya) is one of the branches setup in Libya and consists of four oilfields, which are Bouri oilfield, Bu Attifel oilfield, Rimal oilfield and El Feel oilfield. They are mainly involved in crude oil production throughout the African continent. This research will be applied to the Bu Attifel onshore oilfield which is located in the A100 concession in the Libyan Desert. The field was discovered in 1968 and the production began in October 1972 (Eni, 2008).

The current installation of Bu-Attifel field includes:

Oil Centre Facilities: which consist of the oil wells, manifold, horizontal and vertical separators, tanks and delivery pumps. These parts will covered in this study by applying the mathematical model to optimise the transportation-cost (in terms of reducing the distance from the oil-wells to the manifold) and the simulation technique will applied in the separation area.

Gas-processing Plant: this plant is used to increase the pressure of the gas which is removed from the separation area at different stages. The gas-pressure in the first stage is 700 psi and this gas is delivered direct to the Natural Gas Liquids plant (NGL). The gas-pressure in the second stage is 350 psi and this needs to be increased to 700 psi in the gas plant before it is sent it to the NGL. In the third stage the gas-pressure is 30 psi and this also increased to 700 psi by the gas plant too, and delivered to NGL.

Natural Gas Liquids Plant (NGL): this plant is designed to work with the gas which is removed from the oil in the separators area; therefore the gas is changed to liquid (condensate) under high pressure and delivered to the customer as condensate.

Utilities Plants: these include the water-treatment and power station. The Water-treatment Plant is used to treat the water which is used as drinking water and also for other purposes in the field. The power station feeds electricity to the oilfield.

Oil and gas delivery pipelines: these big-size pipe lines are used to deliver the oil and condensate to the customer from the field to the port.

There are many other facilities in the field which are considered as very important, for example the chemical laboratory, maintenance department and communication department.

The layout details of the production will be discussed in Chapter 5.

1.3Aims and Objectives of the Thesis

Oil production or refinery has several processes and stages which involve transportation, separators and storage-tanks. The overall aim of this study is to develop *an integrated framework to optimise the oilfield production area.* In this environment there are two challenges to deal with, the crude oil transportation and crude oil production area.

The first objective is to optimise the crude oil transportation cost from the oil wells to the manifold in term of distance.

Additionally, the number of wells which will be used or will need to be closed depends on the capacity of the oil-wells and market demand. This situation needs to be optimised in order to fulfil particular demand over a particular period of time in the most cost-efficient way.

The second objective of the thesis is to optimise the productivity and profitability of crude oil area by examining the effect of the some parameters on the performance measures of the production area to increase its productivity and profitability.

The number of production lines, in particular, will be tested to find out not only the number of lines needed to fulfil the demand but also the number of lines necessary to handle the maintenance activities in the real system by distributing the production load on the other working lines.

1.4 The Thesis's Structure

The rest of the report will discuss more about the background of the research and what has been done previously using different methods for the crude oil transportation and crude oil separation. Theories regarding the production operations and methods used by various authors in the past for analysing the transportation-cost and productivity improvement will be discussed more in Chapter Two. Also, in this Chapter, definitions for some of the oil-production jargon will be explained. Chapter Three emphasises the methodology and how the project was carried out, including the general methods that could be used and justification of the used methods.

The oil-wells optimisation model and the results will be discussed in Chapter Four and the simulation models at each stage in the production-area will be discussed and explained in more detail throughout Chapter Five.

Experiments are designed in Chapter Six, and results from the simulation will be analysed and discussed further in Chapter Seven. Chapter Eight will finally conclude the whole project and make recommendations for improvements on the current production systems and operations, followed by ideas for future work on further improvements.

Chapter 2

Literature Review

2.1 Introduction

The previous Chapter introduced the thesis and defined the problems which it will address, followed by information about the Eni Oil Company and Bu-Attifel oilfield which is used as a case study in this thesis. Some ideas were specified about the oilfield facilities and departments. At the end the aim and objectives of the thesis were explained.

The preface to the crude oil transportation, oil-production, crude oil separators and works carried out by previous scientists and engineers for optimisation of crude oil transportation and productivity through different methods will be researched in this Chapter.

2.2 Crude Oil Transportation

The crude oil wells are drilled in the reservoir in different positions and at different distances from the oil separation unit. The crude oil passes through many stages to reach the customer; when the oil is produced from the wells and transported by pipes to the separation unit to separate the water and gas, then it will be ready to delivery to the customer. In crude oil wells sometimes we need to do a massive selection between the wells because most crude oilfields contain a lot of wells. The selection of wells depends on the capacity of the wells, sometimes on the quality of the oil, and also on the distance between the wells area and the manifold.

Figure (2.1) shows example of the distribution of oil wells in the reservoir.

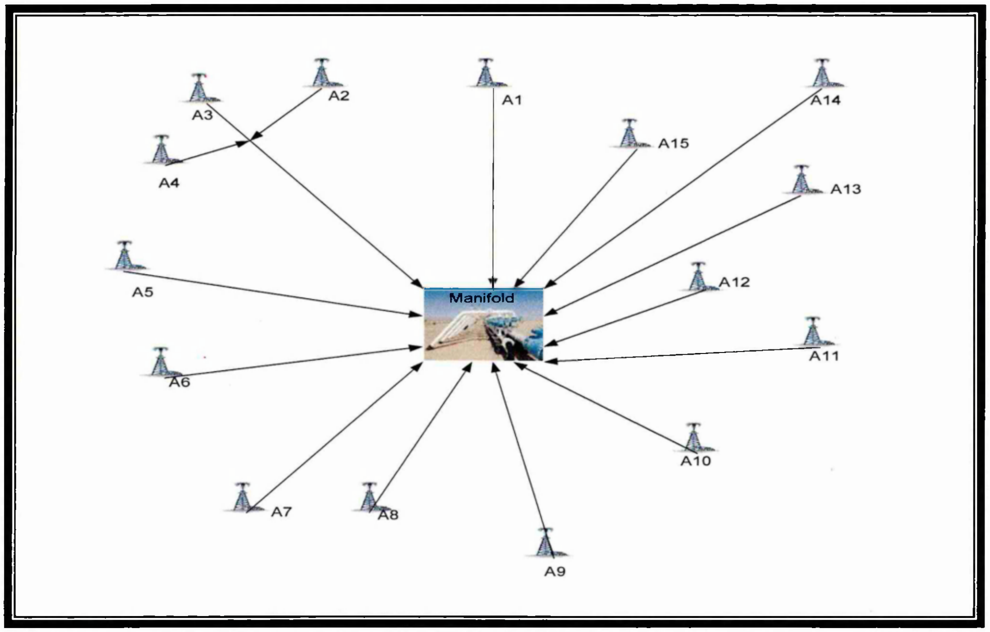


Figure 2.1 Example of crude oil wells distribution

2.3 Crude Oil Transportation Methods:

The major transportation methods, which provide lower-cost transportation of large volumes over long distances, are tankers and pipeline.

- **Pipeline:** a very economical method which can be used to cover long distances, but limited as to route and destination.
- **Tanker:** tankers are used to carry large volumes of crude oil across international waters to link exporting and importing nations.

The determination as to which method is to be used depends on such factors as:

- Distance.

- Crude oil type.
- Cost and availability of alternatives.

Typical total unitary crude transportation-cost is in the range of U$$ 1.50-3.00 per barrel of crude (Cheng et. al. 2004).

To enhance the decision-speed and decrease the transportation-cost, different techniques will be used. One of these techniques is linear programming.

2.4 The Background to Oil Production

Oil and gas have been the main driver of civilisation since the 19th century before the nuclear and computer age started, and they are still playing a significant role in the development of the modern world. They are among the most important commodities in our life as one third to half of the energy consumed is produced from oil and gas. The world is in a technology era and all technology products need energy to function. Energy is needed for the lights, heating, food-growing, industrial applications, transportation, entertainment, etc.

2.4.1 What Is Crude Oil?

Crude oil and natural gas are the raw materials of petroleum and they are the major source of energy supply in the world, though there is now some renewable energy supplied in the market. Crude oil has a mixture of hydrocarbons in different forms and can only be refined through various chemical processing. Asphalt, tar, heatingoils, diesel fuels, kerosene or paraffin, naphtha, petrol, petroleum gases, butane, propane and natural gas methane are all products from the processed crude oil.

They can be classified from densest fractions and lighter fractions depending on their characteristics. According to British Petroleum (1977), crude oil or petroleum naturally contains various individual chemical compounds such as volatile liquid hydrocarbons, otherwise known as gas condensates or non-volatile liquid hydrocarbons, which cannot be distilled due to high molecular weight constituents.

Crude oil found in different zones over the world has its own uniqueness where the proportions of the mixtures and compounds vary from one place to another. Some crude oil has higher viscosity since it contains more semi-liquid hydrocarbons while some contains more gases or water which results in lower viscosity. The quality of the crude oil depends on the proportion of water in it which can give more oil output from the production. There are other factors that dictate the quality of crude oil such as impurities contents, pressure, temperature, etc.

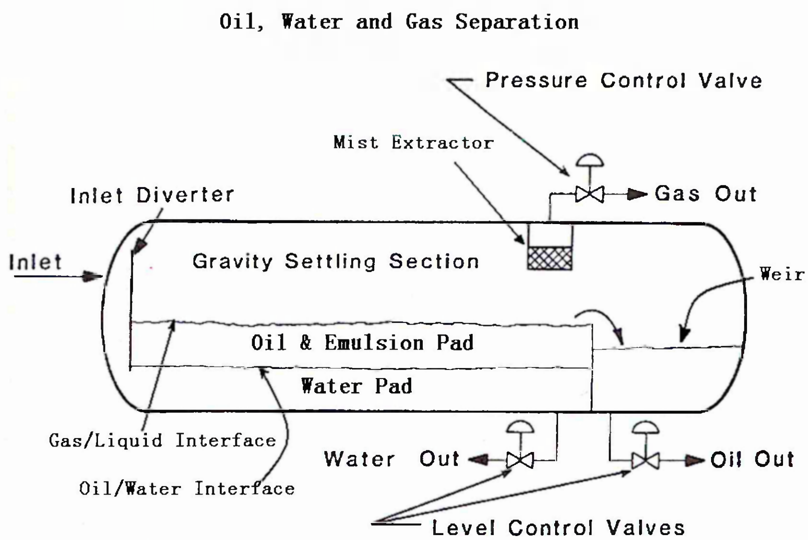
2.4.2 The Crude Oil Separation Process

How does the separation process of crude oil work? Crude oil production starts from the wellhead where control-equipment is installed above the top of the well. Since the crude oil from the wells is in multiphase, it mainly consists of oil, water and gas. Separator tanks are used to separate the crude oil into its constituents. Two types of separators are used in this process, the horizontal and vertical separator as shown in figures 2.2 and 2.3.

(a) (Source: COMPACT, Horizontal Conventional Mist Pad Separators, *Compact*,

(b) (Source: COMPACT, Vertical Conventional Mist Pad Separators, *Compact*,

Figure 2.2 (a) Horizontal Separator; (b) Vertical Separator



(Source: Arnold and Stewart, (1999), pg. 137, altered contents by A. Omer)

Figure 2.3 Horizontal three-phase separator schematic

Crude oil arriving from the manifold is flashed into the separator at high pressure from the inlet and hits the inlet-diverter. This is where the liquid and vapour in the crude oil separate at high momentum. The vapour which contains different chemical compounds flows to the top of the vessel and is extracted from the separator through the mist-extractor. The liquid flows down to the oil/water interface by the down-comer directed from the inlet-diverter.

There are droplets within the gas, oil and water. The gas will contain some liquid droplets which are not yet separated by the inlet-diverter but which will be separated by the mist-extractor and drop into the liquid by gravity-force. The oil droplets in the water will rise above the oil/water interface and the water droplets in the layer of 'oil pad' will settle down below the oil/water interface. The weir is used to maintain the oil level so that the oil is skimmed over the weir. The level controller valves control the level of water and oil downstream of the weir. These processes are repeated through different separators at different pressures until the oil is completely separated from the water and gas at atmosphere pressure. The more detailed processes will be discussed in the rest of the reports. The figures regarding the separators, manifolds, storage-tank and API separator can be referred in Appendix D.

Referring to Table 2.1 and Table 2.2, one third of the crude oil is produced in the Middle East though there are many more other countries involved. However, the major consumers of oil are the United States, Western Europe, Russia, China and Japan. The United States and China have consumed 47 percent of the total oil produced in the world. In fact, the total world crude oil supply decreased in 2006 compared to 2005. However demand keeps increasing. There were some energy crises in the years 1973, 1979 and also price increases in the years 2004 to 2006. Engineers have been trying to come out with better and more advanced technology to refine petroleum over decades ever since industrialisation in the 18^{th} and 19^{th} centuries. While the level of oil reserves are decreasing throughout the world, higher optimisation of oil production systems and facilities is an important solution to the problem, along with sourcing renewable energy which has not yet fully replaced the conventional energy-sources.

Table 2.1 Top World Oil Producers

Top World Oil Producers, 2006 (thousand barrels per day)		
Rank	**Country**	**Production**
1	Saudi Arabia	10,665
2	Russia	9,677
3	United States	8,330
4	Iran	4,148
5	China	3,845
6	Mexico	3,707
7	Canada	3,288
8	United Arab Emirates	2,945
9	Venezuela	2,803
10	Norway	2,786
11	Kuwait	2,675
12	Nigeria	2,443
13	Brazil	2,166
14	Algeria	2,122
15	Iraq	2,008

(Source: EIA, (2006)

Table 2.2 Top World Oil Consumers

Top World Oil Consumers, 2006 (thousand barrels per day)		
Rank	**Country**	**Consumption**
1	United States	20,687
2	China	7,201
3	Japan	5,159
4	Russia	2,811
5	Germany	2,665
6	India	2,572
7	Canada	2,264
8	Brazil	2,217
9	Korea, South	2,174
10	Saudi Arabia	2,139
11	Mexico	1,997
12	France	1,961
13	United Kingdom	1,830
14	Italy	1,732
15	Iran	1,686

(Source: EIA, (2006)

In order to achieve the optimisation, a cost-effective way with more advanced technology should be applied to the design and operations management of oil production area. In fact these complex operations need to be carefully planned to obtain the best methods to reduce the operational cost and guarantee product quality. There are several methods which could be used like linear-programming, inventory theory, non-linear programming, statistical analysis, mathematical solutions, numerical modelling, critical path analysis and computer simulation. According to the research done by several analysts since 1978, computer simulation is one of the methods mostly chosen after statistical analysis as the operation research tool (British Petroleum, 1977).

2.5 Related Literature

"Optimisation or mathematical programming is a mathematical procedure for determining optimal allocation of scarce resources" (Schrage, 2002). Mathematical programming is widely used for modelling with the objective of maximising the profitability or minimising the cost of a process.

Linear programming (LP) is one type of mathematical programming and also is used mostly as a research technique in production and operations management. The term linear programming was firstly introduced by George Dantzig, an American mathematician in 1940. Linear programming techniques were used on very large computers for the operational-phase, supply-phase and planning-phase in BP supply planning (British Petroleum, 1977). The linear programming models were used for the planning of maintenance shut-down, stock-control, etc by refiners to improve productivity and a series of marginal cost-savings was generated in relation to all the refined products to improve profitability.

LP was used in scheduling problems by Ballintijn (1993) in proposing continuous linear programming formulations of the scheduling problems. This led to solutions characterised by an unacceptable amount of switching between different operational modes of unit-processors such as crude-distillers, plate-formers, desulfurisers, etc. However, he developed a mixed-integer programming model that controls the mode of switching at acceptable levels and demonstrated that attractive schedules can be generated with these models.

Giliberti et. al. (1995) presented the methodology to optimise the dynamic simulation of the giant Bu Attifel oilfield (Libya) producing under-water injection for 21 years. Oil-displacement by water and gas flooding was studied by using a two-dimensional numerical black oil model.

Shah (1996) used mathematical programming techniques for crude oil scheduling. Shah showed that it is possible to apply mathematical programming approaches to this economically-important problem. This allowed the specification of a variety of optimisation criteria and a general set of constraints that may be increased or reduced according to the details of individual installations. Since the refinery production plans are usually developed using optimisation techniques, there is also scope for integrating these two facets of decision-making. These techniques may be used in a hybrid approach, where the user could modify interactive schedules proposed by the optimisation.

Carvalho et. al. (1996) developed a numerical model to simulate the operation of a sub-sea separation and boosting system called Petroboost. A computer simulator was built based on the mathematical model developed.

Mathematical programming was used in capacity planning by Taal and Wortmann (1997) focused on solving the capacity problems by improving capacity planning at the MRP level through integration of MRP and finite capacity planning. The planning method was based on a new and more accurate primary-process model, giving the planning algorithm more flexibility in solving the capacity problems.

Jalali et. al. (1997) suggested that the advantages can be identified from the utilisation of process-simulation during the operational phase of an oil and gas separation process. On-line optimisation could also contribute to troubleshooting and surveillance, operation-training and upstream-downstream integration.

Optimal production-planning is one of the most useful tools for a company to stay competitive in the market. A linear programming model for integrated steel production and distribution planning was introduced by Chen and Wang (1997) to formulate the production and transportation planning problem based on the company's system-structure and production-practice. The model was illustrated by a smaller-sized sample and tested by a large-sized realistic problem. Critical analysis was conducted to obtain in-depth knowledge of the system.

Yueming and Halijum (1998) developed a grey integer program model for oilfield development projects on the basis of the theory of the grey system and integer program method. The result showed that the production measures for oilfields could be programmed by using the integer program method. Artificial Nerve Network (ANN) was used with Monte-Carlo stochastic model to program the measures. Linear programming problems needed to be solved for many times in the brand-and-bound method.

Olea et al. (1998) introduced a new methodology to determine the optimal pressure of the stages in the separation of oil and gas. The techniques proposed in this work allow taking better design-decisions, and increase the revenue of the process. Also this paper includes the presentation of a computer program developed in Windows environments, named OPTI_PRE, to simulate and evaluate the separation process with the three mentioned techniques.

In the field of oil and gas optimisation, Fichter (2000) discussed the application of Genetic Algorithms in oil and gas portfolio optimisation. He showed that Genetic Algorithms are excellent at handing accurate and complex non linear business models. Genetic Algorithms are capable of generating multiple good solutions providing an opportunity to explore alternative characteristics of the portfolios, including value and risk measure. This class of algorithms is capable of scaling upwards of a thousand projects, well beyond the reach of traditional methods.

Fraedrich and Goldberg (2000) introduced a methodological framework for the validation of scientific simulation. This framework synthesised the principles from several diversified fields and contained five functional phases for a simulation validation and improvement project. Within this framework, the requirements of the objectives of each phase were stated, and procedures from the model verification and validation literature were cited, where appropriate. Where conventional techniques were not appropriate or optimal, methodological procedures from other field were suggested.

Hansen (2001) discussed the distribution of the multi-phase fluid-flow in a horizontal gravity separator. Computational Fluid Dynamics (CFD) could provide valuable insight, and the fluid-flow behaviour in the liquid volume flow-zone inside the separator was analysed. A phenomenological model of drop-drop collisions and coalescence was described and simulation was performed.

Li et al. (2002) proposed a solution algorithm and effective mathematical formulations for short-term scheduling of crude oil unloading, storage, processing with many oil types, multiple berths, and multiple processing-units. Mathematical programming has been extensively studied and implemented for long-term plant-wide refinery planning. Some commercial software has applied a linear programming model, such as RPMS (Refinery and Petrochemical Modelling System) and PIMS (Process Industry Modelling System), which have been developed for refinery production planning.

Gothe-Lundgren et. al. (2002) described a production planning and scheduling problem in an oil refinery company. The problem was in a distillation unit and two hydro-treatment units. The aim of the scheduling was to decide which mode of operation should be used in each processing-unit at each point in time. Scheduling tools have been developed based on a tabu search heuristic to solve the model, and the schedules obtained have been analysed by experienced planners reflecting on the actual planning situation.

Dong (2003) proposed an integrated modelling framework and methodology for inventory-planning of supply-chains. The modelling framework can be used to model the network topology and capture the interdependencies between model components. A network of inventory-queue models is formulated for the performance analysis of supply-chain with a production authorisation mechanism at all stores.

Khang et. al (2004) introduced a synergetic statistical approach based on field-data to analyse the oscillations of pressure by determining simultaneously the Hausdorff Dimension "D", the Hurst Index "H" and the Entropies "E" as a useful tool for managing the multiphase pipeline transportation system. The results showed that the dimension characteristics of fractal curves, such as the Hausdorff Dimension "D" and the Hurst Index "H" could allow diagnosis of the hydraulic behaviour of oil and gas flows. The synergetic method helped to analyse the dynamic behaviour of oil and gas flows in pipelines based on information collected from daily operations without the need to conduct a costly field-test. Crude oil blending was an optimisation operation, based upon extensive process-knowledge and experience.

Yu et. al. (2004) introduced a new approach to solve the problem of bending optimisation based on historical data, and gave a thorough analysis of the neural optimisation, and real data of oilfields was also used to show the effectiveness of the proposed method. Several authors have pointed out the need to improve the design procedure of conventional oil-water separation.

Lopez-Vazquez and Fall (2004) ran a batch test and various continuums based on a Plackett-Burman statistical plan were performed, in order to optimise small (10L/min) gravity oil-water separator technology intended to pre-treat waste-waters from vehicle service facilities. The work did not present general criteria or generic information for design, instead, it suggested a procedure that could be used to optimise the efficiency and improve the design of existing operation facilities or separators at the pilot stage.

Pettersson and Soderman (2005) presented a model for structural and operational optimisation of a Distributed Energy System (DES). The problem was formulated as a mixed integer linear programming (MILP) problem where the objective was to minimise the overall cost of DSE, for example, the sum of the running costs for the included operations and the annually investment costs of the included equipment. The developed model gave realistic solutions that could be used as a basis for the design of regional distributed energy systems. The application range of simulation techniques has increased in recent years and, consequently, a great deal of high-quality simulation software has emerged in the marketplace with different characteristics and purposes.

Kokal and Al-Ghamdi (2005) discussed challenges related to emulsions that have been encountered in a large Saudi Arabian field. This paper presented the results of a comprehensive study that was initiated to understand the main causes of emulsion formation in the field and investigate ways to optimise oil-water separation. A comprehensive study was undertaken earlier to understand the main causes of emulsion-formation in the field and many factors were investigated, for example water-cut and temperature. The results showed a strong correlation of asphaltene content in the crude oil with emulsion tightness.

Rincon et. al. (2005) proposed a specific set of criteria for evaluating discrete-event simulation software capable of simulating continuous operations. A quality specifications model was developed. The application was demonstrated in one organisation that provided consulting services in the logistics area of the Venezuelan oil industry and it was used to examine four commercial software systems that might fulfil the technical requirements established by the organisation.

Ghoniem et al. (2005) described the construction and use of general optimisation and allocation models for the Khafiji field which simulate the combined performance of the reservoirs, wells and surface-gathering network. Individual well-models and surface-gathering networks have been built from the middle of perforations to separators at gas/oil separation platforms (GOSP). The more accurate multiphase flow correlation has been selected to generate performance curves. These models were calibrated and validated against actual field-data with -1.2% average percentage error, 2.5% average absolute percentage error and 3.5% standard deviation, then lift gas was automatically re-distributed between wells.

Constant-Machado et al. (2005) studied the flow behaviour of crude oil in a battery of industrial crude oil/gas separators in oil industry. The residence time distribution (RTD) of the crude oil has been determined by an impulse injection of ^{113m}IN at the inlet of each separator and the concentration has been continuously recorded at the outlet. The RTD of the crude oil has been simulated by a model composed of a few mixing cells in series representing the effect of the deflector located at the entrance and a plug flow party due to the high viscosity of crude oil.

Carvalho et. al, (2006) proposed an optimisation model for the planning of infrastructure in offshore oilfields. The model determined the existence of a given set of platforms and their potential connection with wells, as well as the timing of extraction and production-rates. The model that represented the infrastructure was a

Mixed Integer Programming (MIP) problem that maximised the net present value which included the revenues as well as the installation, drilling and connection costs. The solution of the MIP was computationally expensive and required different alternative techniques.

Tavares et al. (2006) assessed different strategies for the expansion of Brazilian oil refinery segments, using criteria that range from energy security (reducing imports and vulnerability for key products) through to maximising the profitability of this sector (boosting the output of higher value oil products) and adding value to Brazil's oil production (reducing exports of heavy acid oil). Four criteria were adopted for adding new refineries to the current segment; the initial criterion (energy vulnerability) referred to the logic of minimising the energy vulnerability of the oil chain. The second criterion (minimum-processing) was designed to boost the profitability of domestic oil production. The third criterion (maximum profitability) followed the strategy of maximising the profitability of a refinery on a stand-alone basis, fine-tuning its output for gasoline. Finally, the fourth criterion (petrochemical integration) sought to integrate the refinery with the petrochemical industrial complex refinery focusing on petrochemicals, particularly propane.

Simulation was firstly begun when Georges Louis Leclerc used a needle in the experiment of estimating the value of π (pi), and there was further development until the 1950s when people started to use the FORTRAN language to write computer programs (Kelton et.al, 2007). The application-range of simulation techniques has increased in recent years and, consequently, a great deal of high-quality simulation software has emerged in the marketplace, with different characteristics and specific purposes. Today, there are many higher-level programming languages created like GPSS, Simscript, SLAM, SIMAN, C/C++ Code and VBA, which provide better functionality to create the simulators. By applying these languages in the simulation tool, a more user-friendly interface and more advanced model can be created.

2.6 Conclusion

In this chapter the transportation of crude oil was studied by giving an account of different kinds of crude oil transportation, and how the transportation-cost of crude oil from the oil-wells to the manifold could be decreased by using linear programming technique.

Crude oil production is discussed which includes the different kind of separators that are used in crude oil production. Top world oil-producers and consumers were studied by introducing the largest producer and consumer countries in the world. Also in this chapter the previous studies which were carried out by scientists and engineers in the field of mathematical programming and simulation were described to prove how these techniques were used widely to solve many problems or to improve productivity in different fields.

Based on the literature review, it is clearly that there were shortage and gabs in researching the oil wells and the oil production areas individually and most importantly there was no intention in the literature to consider these two problems as an integrated problem to reflect the reality of this environment. Therefore, the aims and objectives of this thesis proved to be valid and needed to help the practitioners to make the right decision at the right time.

The next chapter will describe the methodology which will be used in this project and explain why the decision is taken to use these techniques. The framework which is developed to optimise the crude oil production will be discussed in the next chapter too.

Chapter 3

Research Methodology and Proposed Framework

3.1 Introduction

In the previous chapter, works carried out by previous scientists and engineers for the optimisation of crude oil transportation and production by different methods were reviewed. The different kinds of separators which are used in crude oil separation were discussed.

In this chapter, research methodologies in general and the carefully chosen methods used in this thesis are presented. In addition, the proposed framework for the optimisation of the oilfield production-area is introduced.

3.2 Mathematical Programming Histories

Optimisation or constrained optimisation, or mathematical programming, is a mathematical procedure for determining optimal operational policies for the available resources. The most popular special form of optimisation is Linear Programming (LP). The petroleum industry was an early intensive user of LP for solving fuel-blending problems (Schrage 2002).

Occasionally tens of thousands of constraints have been built. These models are used to help make a number of decisions starting with where and how to buy crude oil, how to ship it, and which products to produce out of it. A typical example of the kind of model which arises in the industry is the refinery optimisation. This technique is also used in the chemical industry in different operational methods similar to those used in the petroleum industry. In the manufacturing industry Linear Programming is frequently used for resource-allocation. Resources to be allocated are usually processing-capacity, raw materials, and man-power. A multi-period problem of this type, measured in relation to the engineering industry, is the factory planning. Other common applications of LP in manufacturing are in the steel industry (blending and blast-furnace burdening). Also the problem of distribution can often be formulated as LP models.

In finance due to Markowitz (1959) a very early application of mathematical programming was in the *portfolio section*. This was given a sum of money to invest; the problem was how to spend it between a portfolio of shares and stocks. The purpose was to keep a certain expected rate of return from the investment but to minimize the difference of this return.

Agarwala and Goodson (1970) proposed how LP can be used by governments to design an optimum tax package to achieve some essential aim (in particular a development in the balance of payments). This was an example of LP usage in finance, but it is used for many other purposes.

In agriculture LP has been used for farm management. Such models can be used to decide what to grow where, how to rotate crops, how to expand production, and where to invest. In mining a number of applications of mathematical programming take place. The simple applications are simply ones of resource allocation, i.e. how should manpower and machinery be deployed to best effect? In manpower planning, by using linear programming it is possible to move people between different types of job and to control recruitment, promotion, retraining, etc The food industry makes wide use of linear programming, blending (sausages, meat, pies, margarines, ice cream, etc.) is a clear application regularly giving rise to very small and easily-solved models. In Energy, both the electricity and gas supply industry use mathematical programming to deal with problems of resource-allocation. Linear Programming was used in the manufacture of paper in resource-allocation. In addition, recycling waste-paper has also been examined by Linear Programming as described by Glassey and Gupta (1974). Linear Programming is also used in media-scheduling problems e.g. television commercials, newspaper advertisements, etc (Williams 1999).

Further to this introduction about Linear Programming usage, please note that the main aim of the different kinds of industry is to enhance their productivity and profitability by using different techniques which lead to a reduction in costs.
In the oil industry it is vital to decrease the cost of oil-production from the extraction of crude oil from the reservoir to delivery to the customer.

In fact these complex operations need to be carefully planned to obtain the best methods to reduce the operational cost and guarantee product quality.

3.3 Transportation Model

A special case of Linear Programming is the transportation model that deals with shipping a product from source (e.g. factories) to destination (e.g. warehouses).

The objective of using the transportation model is to determine the shipping schedule that minimises the total cost of shipping (Taha 2003).

In this part of my study the transportation model will be applied to minimise the cost of the transportation of crude oil from different oil-wells (the source) to the manifold (the destination). The decision was taken to use Mathematical Linear Programming because mathematical programming is superlative for crude oil transportation, and during the study of the problem it presented linear equations. Also the software (Ling & Lindo) which will be used to solve the equations is available at the university.

3.3.1 The Problem with Mathematical Solutions in Crude Oil Production

Crude oil wells are drilled in the reservoir in different situations and at different distances from the crude oil facility. Therefore, the wells are connected by pipes from the wells to the crude oil facility. The distance and also the productivity of every well is different and the oil could be of different quality. A mathematical model will be used in this thesis to optimise the transportation-cost in terms of the distance between the oil-wells and the manifold (crude oil facility) by using two variables, distance and oil-well capacity.

3.4 Methods Available for Research in General

3.4.1 Mathematical Modelling

According to Maki and Thompson (2006), mathematical models are neither physical nor logical, while Kelton et.al (2007) considered both logical and mathematical models as the same concept. To be more precise, the logical models are used specifically in defining the undefined terms, axioms and abstract thinking; in short, the abstract systems. Logical models can be analysed numerically by using the mathematical models through mathematics, theories, differential equations, and partial-differentiation equations. Mathematical models consist of system elements such as variables, symbols, parameters and factors that are relevant to the modelling of real systems, and normally expressed in terms of equations. However, it is not necessary to use equations at all times. There are scenarios where some of the system elements are unquantified and can be represented by using diagrams and tables. A mathematical model is also a set of processes with approximations and assumptions attempting to match observations with logical or symbolic statements.

Mathematical models can be studied analytically by using calculus or numerically by using computation programming or coding, called computational models. The mathematical models can be created to explain the observations, to predict different kinds of goals, to facilitate decision-making or a combination of any of these. For example, the first order differential equation of speed $f(x) = dx/dt$, where dx is the change of distance and dt is the change of time.

When applying a mathematical model in the oil-production area, complicated mathematical models are used for describing the coalescence and settling of oil and water-droplets in multiphase separators. Sayda and Taylor (2007) listed a number of parameters, variables and factors such as "separator dimensions, flow-rates, fluid physical properties, fluid-quality and drop-size distribution" which will be taken into account when developing the mathematical models.

3.4.2 Heuristic Modelling

The word 'heuristic' comes from a Greek word 'heuriskein' which means to find or discover. Archimedes used this word 'eureka' which means 'I have found (it)' long ago. In engineering, 'heuristic' refers to the methods or ways that are used to seek immediate solutions in a short time. A heuristic technique can be defined as "a technique which seeks good (i.e. near optimal) solutions at a reasonable computational cost without being able to guarantee either feasibility or optimality, or even in many cases to state how close to optimality a particular feasible solution is" (Reeves, 1993).'Heuristic' means using, or obtain solutions by, informal methods or reasoning from experience, often because no precise algorithm is known or is relevant. It involves trial and error, as in iteration. Also a huge amount of work has been done on heuristic methods for solving combinatorial problems. It has been used as a new method in forecasting oil-production throughout the world, as a variable neighbourhood search (VNS) heuristic for scheduling work on oil-rigs, and it is also popular in Social Science modelling (Aloise et. al, 2006).

3.4.2.1 The Disadvantages of Mathematical Modelling and Heuristic Modelling

For a real situation representation, mathematical models are mostly simplified and idealised to identify the most important parts to be modelled, especially in the prediction of outcomes which is called 'real model'. The accuracy and precision of predictions, decisions and explanations provided by using mathematical models are expected to be high when dealing with complex systems. Nevertheless, the more complex the systems are, the more difficult a mathematical model must be constructed. Here is where the simulation model could be introduced. As Kelton et.al, (2007) mentioned, most of these complex systems may not be worked out by exact mathematical models, but simulation can help.

A heuristic model could give quick solutions to the problems or be useful in the preliminary modelling design but there is concern that it is likely to be erroneous and unable to guarantee accurate solutions to problems.

3.4.3 What is Modelling?

A group of objects, ideas and the behaviours of different systems and processes can be represented in various ways. Modelling is one of the ways to represent them and it is no longer a new terminology to us. A model is a set of objects which represent the real process or systems, which could be physical or logical. There are also other definitions of the word 'model' from different people. According to Neelamkavil (1987: pp. 30), "a model is a simplified representation of a system (or process or theory) intended to enhance our ability to understand, predict, and possibly control, the behaviour of the system".

"' 'System' is a collection of parts organised for some purpose" (Coyle 1996). Mental, physical and symbolic forms are the three main types of systems described by Neelamkavil (1987). The mental form is used more for representing the thinking or behaviour of living creatures in the mind of individuals. The physical form is used for representing a tangible object which can be seen and touched and normally exists in three-dimensional medium. The symbolic form of modelling is more commonly used in the scientific or engineering field including numerous symbols, pictures, maps, variables and constants representing equations and formulations. Checkland (1981) identified four main types of systems which are natural systems (e.g. weather systems), designed physical systems (e.g. a train), designed abstract systems (e.g. mathematics) and human activity systems (e.g. a community). Maki and Thompson (2006) on the other hand differentiated the types of model in more detail by the nature and behaviour of the systems and processes to be imitated. They included physical models, theoretical models, logical models, computational models, simulation models and mathematical models.

3.4.4 Computer Simulation Modelling

Computer simulation is a process of designing a digitised model representing a real or proposed system for the purpose of experimentation and understanding of the system's actual behaviour with given factors and scenarios. Compared to other approaches such as the mathematical model and heuristic model discussed before, computation simulation can be used to study simple systems but it is preferable when dealing with more complex systems. "Simulation involves the modelling of a process or system in such a way that the model mimics the response of the actual system to events that take place over time" (Schriber, 1987). Once the system's behaviours are studied and analysed, improvements can be carried out by simulating the model using different input-data, in short the pilot-testing, which is also called the 'what-if?' analysis tool.

The systems to be modelled and simulated could be any kind of system described in section 3.4.3 Weather forecast systems are modelled with the latest data as variables and simulated for prediction of the future weather. It could be a few hours or days ahead. The latest version of data provided will decide the accuracy of the weather systems model due to major uncontrollable inputs from nature. The simpler the model is, the less accurate the end results shown. Historical data can be added for analysis of the predicted weather.

3.4.4.1 The Advantages of Computer Simulation

In experiments carried out on real systems and simulations, the competencies of simulation tools versus the other approaches and the quality of decision making are the main areas where the benefits of simulation can be explored.

1. *Cost Saving*

In real systems, experiments for testing the improvements designed could be costly and time-consuming, especially in production operations systems. If the experiments are taken place in the real crude oil production systems, some of the production-lines might need to be closed down. In the oil production plant, the cost for closing down production-lines can be sky-high, estimated at over millions of pounds.

2. *Time-saving*

Apart from the cost-saving, time spent on experiments with simulation models could be from seconds to hours or days depending on the types of software tools and computers used. It could even take from weeks to months or years for special systems like ecology. Some of the high-level simulators showed significant time-saving compared to the simulation by programming languages.

3. *A Comparison of Different Scenarios*

While simulating the models, different scenarios can be set up and tested. These experiments can be repetitive and compared with their performance and results throughout the operations. For example, two types of production plant layout could be simulated and compared simultaneously or by analysing the results at the end of simulation for comparison.

4. *The Impossibility of Real System Construction*

There are cases where the real system is not yet constructed, therefore the simulation is needed here to carry out the testing and experiments for validation beforehand to avoid failures and profit-loss. Before a chemical plant is constructed, all kinds of processes and equipments within the plants have to be planned, designed and tested to ensure they are working.

5. *Wide Areas of Implementation*

Simulation is suitable for simple and complex systems. It can be used in operating procedures, decision-rules, organisational structures, new hardware designs, physical layout, transportation systems, etc for exploring and testing without interrupting the ongoing systems.

6. *Answering 'What-If?' Questions*

A simulation can be used to simulate the model and make changes to the model to run for 'what-if?' questions. For example in crude oil production, for questions like 'What if one of the production-lines closed down, would the output be affected?' the simulation model data can be altered to predict the output for this question.

7. *The Competencies and Ease of Use for Supporting Decision-making*

Most of the modelling will need certain assumptions when designing the complex systems due to their inability to add in numbers of variations. Although simulation does need some assumptions made, it is possible to insert any kind of distribution to model complicated systems while still giving satisfying results and predictions. Animation displays in simulation tools could enhance the application for non-experts and facilitate the decision-making for the managers. Users are able to stop or run the simulation step by step for more interaction and understanding of the process and events happening in the model.

As an example, in food-store operations management, the operations manager has to predict the customer buying-behaviours and make orders based on these, though historical analysis is essential. It is impossible for the manager to control the buying time, quantity and products which customers want. The only thing the manager can do is analyse the historical sales data and simulate the systems using various variables and distribution to represent the dynamic behaviour of customers. The other areas where simulation can be applied are public systems like health-care, education systems, transportation systems like train-scheduling, and food-service systems like restaurants, business process-management, etc.

3.5 The Computer Simulation Method

Through the analysis of the disadvantages of other modelling methods and the advantages of simulation-modelling, the simulation-modelling method or, to be more precise, computer-simulation was chosen for this project due to its powerful ability in dealing with complex systems. The use of computer-simulation in the oil and gas industry allows managers or engineers to obtain a system-wide view of the effect of local changes to the production area; and computer-simulation played a vital part as a real-time controller for the design, analysis, development and implementation of the proposed integrated framework for this project.

3.5.1 The Purpose of Simulation

The operation of a system is subject to variations either predictable or unpredictable (Robinson, 2003), which both might give changes to the system when altered. In simulation, these variations are called 'variability'. Presence of more variability in a system brings on more complexity to the modelling. Modelling designers normally tend to simplify the system or study only one particular aspect of the system due to the complexity caused if all interconnections of the variability in the system are taken into account. There are also some 'variables' included in the simulation for representation of time, ratio, and any kind of numerical data. However, if the model of the system is simplified to ease the design, it is more likely that the study will be inaccurate as a result.

Computer-simulation is used in the oil industry by Yamamoto et al, (2000) to optimise offshore oil production based on discrete event modelling. The authors have developed a new simulator to make an integrated simulation of the overall system, which contains offshore oil production wells, a floating structure production facility, shipment facility, sea vessel, and land equipment considering the weather conditions.

Computer-simulation has the ability to cope with the complexities of complicated real systems. Several reasons for implementing such simulation can be concluded as below:

1. It is a less-expensive research and study method compared to experiments carried out in real systems.
2. Advances in software-technology and programming-language improve the software power for rapid and valid decision-making.
3. Training can be carried out without affecting the real operations for operators.
4. Animation in simulation models advances the visualisation of operations systems for better understanding.

3.5.2 Types of Simulation

Time and variability are the two most important aspects when designing a simulation model. Kelton et.al, (2007) has classified the types of simulation into three main classes which are static vs. dynamic, discrete vs. continuous and deterministic vs. stochastic.

1. Static vs. Dynamic Simulations

Static means 'in a fixed or stationary condition'. In the static model, "time does not play a natural role, but it does in a dynamic model" (Kelton et al, 2007). For example, throwing a dice need has no relation with time but number of throws. On the other hand, the dynamic model, like the opening of a post office, has an opening time and closing time. Time is playing a role in this model.

2. *Discrete vs. Continuous Simulations*

The main difference between discrete and continuous models is the type of change in the system either over time or at specific time. Events in a discrete model will only change at a specific defined time, for example, bread is cooked for 30 minutes. There will be a starting time and ending time here. In the continuous model, the event will change over time according to the rate of change. This is normally used in a case like weather changes. The pressures and speed of wind change continuously over time. There are occasions where the discrete and continuous models are combined, for example "the refinery with continuous changing pressure inside vessels and discretely occurring shutdowns (Kelton et.al, 2007)."

3. *Deterministic vs. Stochastic Simulations*

Most of the time before the simulation is carried out, there is a possibility the results are known. The deterministic model does not have any random inputs and the outputs are within the expected spectrum. Two kilograms of flour can bake four loaves of bread weighing 750 grams each, or "a strict appointment-book operation with fixed service times is an example (Kelton et.al, 2007)." In a stochastic model, random inputs will determine the outputs by using distribution or probability. An example is how random arrivals of customers in a food-store vary all the time.

3.5.3 Issues Related To Simulation and When Simulation Is Used

There are some issues to be considered before deciding to use computer-simulation in the systems where operations taken place. In the past, simulations were not often adopted in business due to expensive and specialised tool requirements. A huge amount of time and investment were needed in simulations-implementation. But they might be used in big organisations; heavy duty and automotive industries adopted simulations to solve only the serious problems which arose in the operations.

Nevertheless, thanks to the advancement of the software and computer-technology, the simulation tools were designed to be more user friendly. There was greater integration with other software packages like spreadsheets, word-processors, and databases over the years where simulations could be applied in more detail and in more specific markets or processes for collecting data, analysing data and storing data. Simulation could be developed into new system-control logic by the design or redesign of complex systems for controlling real systems, as mentioned by Kelton et.al, (2007).

Simulation can be applied in various types of systems and industries such as manufacturing or any kind of production operations. Simulation can also be used for planning new equipment and buildings-layout for improving efficiencies and the production of new products. It can also be used for upgrading existing equipment and operations to increase efficiencies. For example in our case-study the oilfield is working perfectly, but this study aims to improve the productivity of the separators and also modelling the system helps to improve the decision-making. There are many more areas that can be simulated for more specific and detailed evaluation.

3.5.4 The Simulation Process

The simulation process consists of a number of different procedures. The following framework is used:

1. Problem Formulation
2. Data-gathering and Conceptual Model Development
3. Model Construction
4. Model Verification and Validation.
5. Experimental Design and Results Presentation
6. Results Analysis
7. Documentation and Implementation

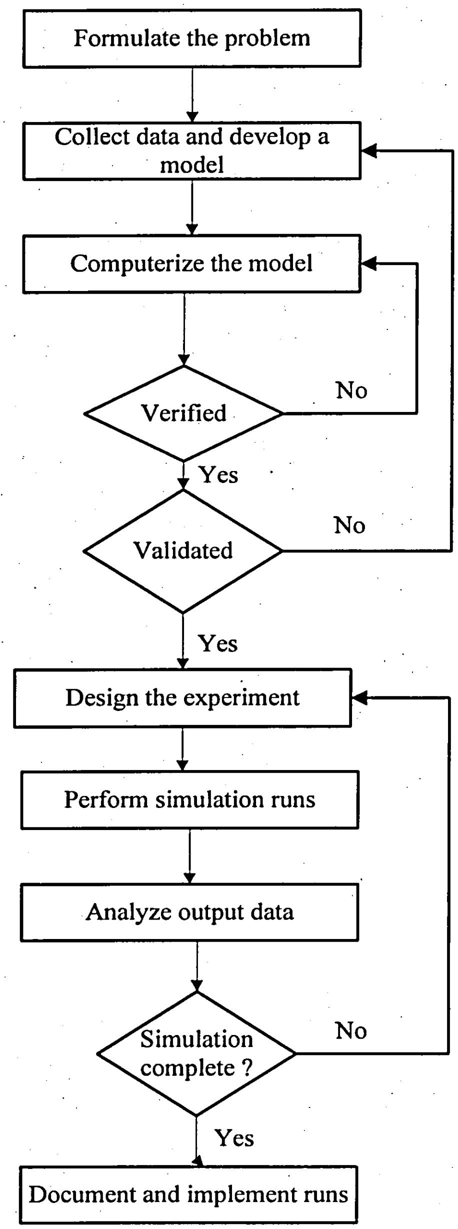


Figure 3.1 Framework in Simulation Study (Winston 2004)

3.5.5 Simulation Tools Available

There are a few types of simulation tools available for research and implementation in general, depending on the types and behaviours of the systems to be modelled and simulated. According to Robinson (2004), there are three options for developing computer-simulation models which are spreadsheets, programming languages, and specialist software.

The programming languages allow the programmers or modellers to create some sort of logic and programmes that make it easy for the users who have no programming knowledge to perform some kind of calculations, analysis, designs, for performing repetitive jobs; or they can be used later to do simulations using computers. Programming languages like C, VB, C++, Java and VBA are high level languages and they are widely used in recent computing technology. Historically, "FORTRAN the general-purpose procedural language had been used to write computer-programs for simulating complicated systems with supporting packages written to help out in routine chores, keeping track of simulated events and statistical bookkeeping" (Kelton et al, 2007).

Spreadsheets can be used to display data in columns and rows. Formulas can be inserted for calculations. For example, when there are many numbers or data to be added up, the formula 'SUM' can be used to sum up all the data required without calculating each of them manually. Spreadsheets software like Microsoft Excel applications can be used to simulate very simple static-models supported by the programming language used in Excel, the Visual Basic and some other add-ins for better control. However, spreadsheets are limited in their ability and integrity in modelling dynamic models.

Using the tools described above, the specialist software or simulator on the market which is programmed with high-level programming language can be used to implement modelling and simulation.

3.6 ARENA Simulation Tool

The ARENA software package supplied by Rockwell Software is selected as the simulation-tool for this project. Arena was selected as the simulation-tool for this project owing to the criteria shown in figure 3.2. The time available for obtaining modelling-skills, building the model and model validation was restricted. The knowledge of the modeller of continuous-simulation modelling was limited, although previous experience in modelling discrete systems was useful as the basic of using this software. The run-speed of the simulators was another important factor in the effectiveness of the simulation in this project. The Arena professional version was available in the university; therefore the price of the software packages was negligible. Therefore the five criteria shown in figure 3.2 are extremely important to the success of this simulation project.

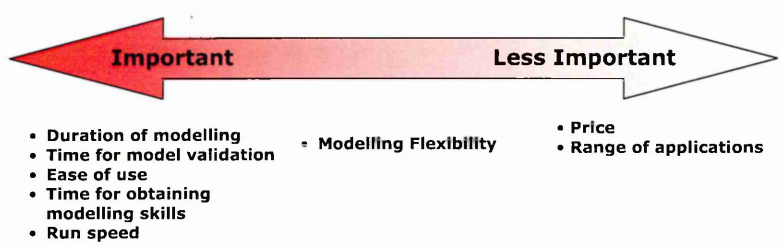


Figure 3.2 Important Criteria for the Proposed Model

The Arena software package was initially installed in the computer as the student version which can support simple and small-model testing. However when it came to the later part of the modelling with more complexities, the professional version was required to support the number of modules and variables designed. Arena combined most of the advantages of high-level simulators, simulation-languages and general-purpose procedural-languages like Microsoft Visual Basic programming and C language. Therefore, it is able to provide ease of use, and high and low-level modules from different templates for different functionality in one model. Due to its greater integration between spreadsheet and general-purpose procedural-languages, Arena can import and export data to spreadsheet by using some programming-language like VBA.

3.6.1 Arena's Framework

Figure 3.3 shows the pieces in the Arena window for the model of this project. This section will introduce the framework and interface of the Arena software. Detailed guidance on how to use the software can be found in the Arena software help-page or from Kelton et al, (2007).

The tool bar has many different short-cut buttons for ease of control while building the model. Many of the functions and tools can be found in here or through the menu bar. In the project bar are found the templates and modules used for the modelling as mentioned in Figure 3.3. In this research, the main template-panels which were used were the Blocks and Elements Panel, Basic Process Panel, Flow Process Panel, and Advanced Process Panel. The contents and modules which were used will be discussed in Chapter Four where the model description takes place.

The model-window, Spreadsheet View, provides the convenience of altering the details or contents of the modules used without going into each of them. The status-bar will show the data, time, status and number of replication for the simulation. Therefore, users are able to understand what has been happening at the time shown in there. While the model-window, Flowchart View, is where the models are built, and what is shown in this model-window are the animations and model-logic for this research.

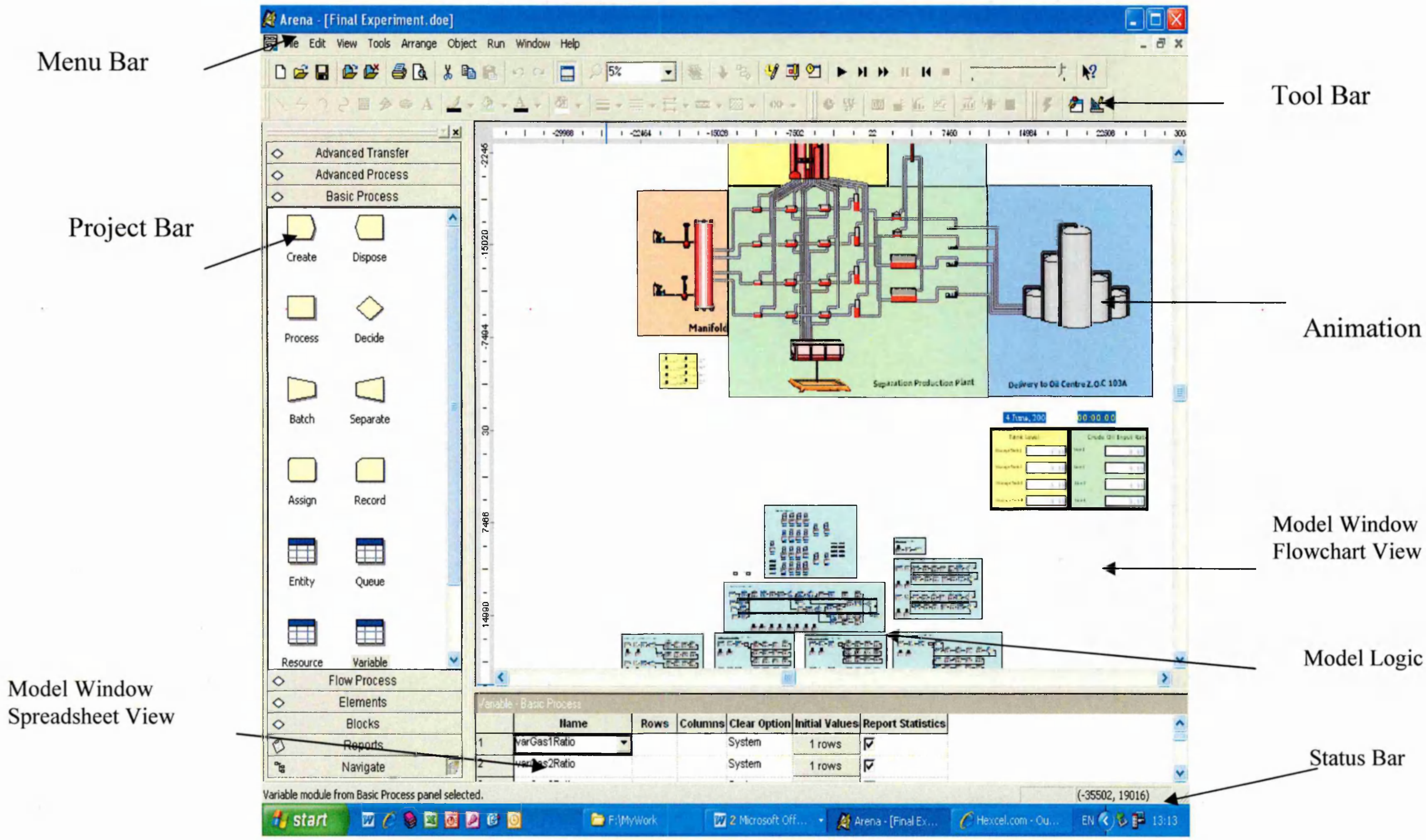


Figure 3.3 Arena Window for the Simple Processing System

3.7 The Proposed Framework for the Optimisation of the Oilfield Production Area

Oil field is a place where the crude oil produced and treated to remove water and gas. The oil field consists of many facilities in which oil wells and oil separators (oil production area) are considered to be the most important areas. There are also other facilities such as power station which provide electricity to the field, water treatment equipment used to supply the field with the water which is used in the production area.

This study is focusing on two main areas of the field which are oil wells and oil production areas.

When the drilling process in the wells finished and the charismas tree is fixed on the well head, the wells are contacted through pipes to the manifold. The crude oil arrive to the manifold from the wells consists of water and gas, therefore to improve the quality of oil, the gas and water must be removed.

When the oil reach to the manifold, then it should be distributed to different separators to remove the water and gas (production area), and this considered as second main base of the field.

As can be seen there are two main stages, first stage is the transportation of oil wells to the manifold then distributed to the separators in the oil production area. Naturally, these two stages are linked together and optimising any of these two stages has to be carried out on this bases. Therefore, an integrated framework for this environment is developed to reflect this reality and is shown in figure 3.4. The framework has been developed to consider these logical steps in operating the whole site and provide the operational policies needed to operate both areas in an integrated approach.

Figure 3.4 shows the proposed integrated framework for the optimisation of the oilfield production area. The framework includes three different components.

The first component concerns the oil-wells area in which the aim is to minimise the transportation-cost of the oil from the wells to the manifold area. As can be seen in figure 3.4, the problem will be formulated mathematically in the form of objective function(s) and constraints. It will be solved using the Lingo/Lindo application. The expected outcomes will be either an optimum or near-optimum solution. This solution will be fed into the second component which is a representation of the oil production area in a form of a simulation model. In this component different operational policies will be evaluated. The third component is the analysis of the results and this checks their validity in terms of the company's strategic performance measures. These will give the opportunity to modify the operational policy by either changing the parameters/variables in the oil-wells area or in the production area until an acceptable operational policy is agreed.

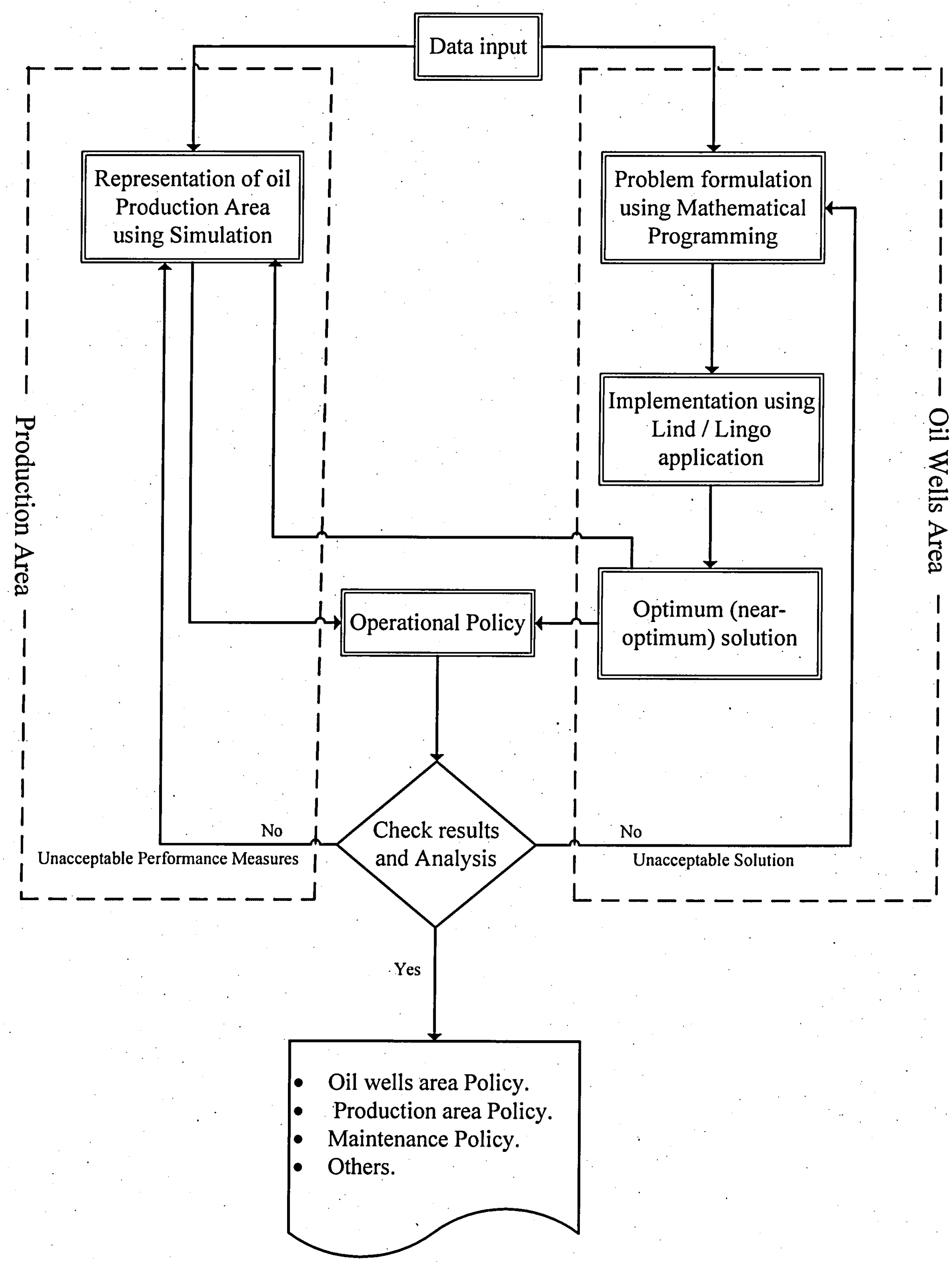


Figure 3.4 The Proposed Integrated Framework

3.8 Conclusion

In this chapter the methodology which will be used in this project was discussed. A mathematical model will be used in the oil-wells area and the simulation technique will be used in the separators area. Previews were given about both techniques, which include the history of mathematical modelling and simulation techniques. Also the reasons for using these techniques and advantage and disadvantage were discussed. Furthermore, this chapter briefly discussed Arena software, which will be used in the simulation of the separators area. Finally, the framework which will be used for the optimisation of the oilfield production area was discussed.

In the next chapter, the mathematical optimisation model of the oil-wells area will be introduced, which includes the model-presentation and model-solving by Lingo software. In the end the results of the model will be discussed.

Chapter 4

Oil-well Optimisation Model

4.1 Introduction

The theories regarding the simulation-modelling and crude oil production-processes explained in previous chapters should have provided some understanding of how the crude oil is separated and what sorts of simulation-tool can be used to model such systems. The framework developed for the optimisation of the oilfield production area was introduced and explained too.

The mathematical model for the optimisation of the oil-wells area will be discussed in this chapter. This chapter consists of the oil-wells model presentation, proposed mathematical optimisation and also the case-study modelling which is based on the Bu-Attifel oilfield in one of the developing countries. Using Lingo/ Lindo software will solve the mathematical model and the results will be discussed.

4.2 Model Presentation

Mathematical programming will be used to minimise the transportation-cost of crude oil from the oil-wells to the manifold. The following issues are considered in developing the mathematical programming model for crude oil wells:

- The capacity of the crude oil wells (supply).
- The distance from the oil-wells to the manifold.
- Customer demand at the manifold (demand).

The crude oil is produced from different oil-wells, transferred to the manifold through pipes over different distances, and the oil-wells have different capacities.

In general, an optimisation model will consist of the following three items:

Objective Function: The objective function is a formula that expresses exactly what it is you want to optimise. In this part of the study the transportation-cost of crude oil from the oil-wells to the manifold will be optimised.

Variables: Variables are the quantities you have under your control. You must decide what the best values of the variables are. For this reason, variables are sometimes also called decision variables. In this study x_{ij} represents the amount of oil produced from well i to manifold j.

Constraints: Almost without exception there will be some limit on the values of the variables. In this study there are two constraints: the first supply constraint is that the amount of oil produced from wells to the manifold is >= the demand at the manifold. The second constraint is the capacity constraint, which is that the amount of oil produced from every well to the manifold is <= the capacity of every well at the manifold.

4.3 Proposed Mathematical Optimisation Model

In presenting the mathematical programming model, the following notations are used;

Indices:

i = 1, 2, 3 ... The number of oil-wells

j = 1, 2, 3.... The number of manifolds

x_{ij} = The amount of oil provided by well (i) to manifold (j)

C_i = The capacity of oil-well (i)

C_t = Total capacity of oil-wells

S_{ij} = The distance from oil-well (i) to manifold (j)

d_j = The demand at manifold (j)

The mathematical model will be used to optimise the transportation-cost of crude oil (in term of distance) from the oil-wells to the manifold. To solve this issue the problem must be formulated as equations. The aim is to minimise the transportation-cost from the wells to the manifold. That means minimise the distance which is S from the wells i (any number of wells) to the manifold j (any number of manifolds) and multiplied by x which is the amount of oil provided from the wells to the manifold. This equation is considered as an objective function.

Now the variables are the quantities you have under your control. You must decide what the best values of the variables are, so, x_{ij} represents the amount of oil produced from well i to manifold j.

$$\text{Min. } \sum_{i=1}^{m} \sum_{j=1}^{n} s_{ij} x_{ij} \qquad i = 1....m. \text{ Number of oil wells.}$$

$$j = 1...n. \text{ Number of manifolds.}$$

The constraints will be some limit on the values of the variables which is represented by these equations below. In the first equation the amount of crude oil from the oil wells (x) is bigger than, or equals, the demand (d_j) at the manifold. In the second equation the amount of oil (x) is less than, or equal to, the capacity (C_t) of the oil wells. The last equation is representing the amount of oil (x) when it equals the demand at manifold (d_j).

Subject to:

$$\sum_{i=1}^{i=m}\sum_{j=1}^{j=n} x_{ij} \geq d_j$$ d_j = Demand at manifold

$$\sum_{i=1}^{i=m}\sum_{j=1}^{j=n} x_{ij} \leq c_t$$ C_t = Total capacity of oil-wells

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} = d_j$$ d_j = Demand at manifold (j)

In the case of:-

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} > d_j$$ Then, Supply > Demand

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} < d_j$$ Then, Supply < Demand

4.4 Modelling the Bu-Attifel Oilfield

In this study Bu-Attifel oilfield which belongs to the Eni Oil Company Libyan branch, will be used as a case-study. To facilitate the application of the mathematical model proposed in the previous section, it will be applied in a real case-study (Bu-Attifel Oilfield).

Table 4.1 displays the collected data which consists of well-numbers presented in column one starting from A1, to A83. It may be noticed that the numbers are not in series as it is real data and a possible reason for this is may be that these missing well-numbers were dead. In the second column the first manifold is represented and x_{11} mean the amount of oil provided from well number 1 to manifold number 1; also in the same column the distance, *(S11)* represents the distance from the well number 1 to manifold number 1. The third column represents the second manifold, and x_{12} means the amount of oil received from well number one to manifold number two. Also (*S12*) is the distance from well number one to manifold two.

The capacities of the oil-wells are represented in column four where sub-column one represents the capacity of gas produced from every well. The amount of oil and water produced from every well is presented in the second and third sub-columns respectively. The last column represents the total production of every well (gas, oil, and water).

Table 4.1 Bu-Attifel Oilfield Oil-wells information (cont.)

TO / From	Manifold 1 (mtrs)	Manifold 2 (mtrs)	Capacity			
			Gas(scf/stb)	Oil(BOPD)	Water(BWPD)	Total
A1	*S11* $x_{1\,1}$	*S12* x_{12}	3,220	2,607	892	C1
A3	*S31* $x_{3\,1}$	*S32* x_{32}	15,895	111	8,315	C3
A4	*S41* $x_{4\,1}$	*S42* x_{42}	1,780	3,270	7,496	C4
A7	*S71* $x_{7\,1}$	*S72* x_{72}	1,984	2,283	2,444	C7
A8	*S81* $x_{8\,1}$	*S82* x_{82}	4,204	145	6,257	C8
A11	*S11* $x_{11\,1}$	*S112* x_{112}	0	0	782	C11
A13	*S131* $x_{13\,1}$	*S132* x_{132}	2,381	3,221	4,294	C13
A14	*S141* $x_{14\,1}$	*S142* x_{142}	583	1,778	583	C14
A15	*S151* $x_{15\,1}$	*S152* x_{152}	1,815	2,524	6,612	C15
A16	*S161* $x_{16\,1}$	*S162* x_{162}	2,350	601	3,336	C16
A17	*S171* $x_{17\,1}$	*S172* x_{172}	1,547	10,761	2,298	C17
A19	*S191* $x_{19\,1}$	*S192* x_{192}	2,496	1,835	5,613	C19
A20	*S201* $x_{20\,1}$	*S202* x_{202}	2,692	505	5,214	C20

TO / From	Manifold 1 (mtrs)	Manifold 2 (mtrs)	Capacity			
			Gas(scf/stb)	Oil(BOPD)	water(BWPD)	Total
A21	*S211* $x_{21\ 1}$	*S212* $x_{21\ 2}$	1,710	3,598	3,338	C21
A22	*S221* $x_{22\ 1}$	$x_{22\ 2}$ *S222*	2,669	6,422	3,172	C22
A24	*S241* $x_{24\ 1}$	*S242* $x_{24\ 2}$	2,943	1,319	0	C24
A25	*S251* $x_{25\ 1}$	*S252* $x_{25\ 2}$	1,549	8,578	1,348	C25
A27	*S271* $x_{27\ 1}$	*S272* $x_{27\ 2}$	1,935	1,101	1,275	C27
A28	*S281* $x_{28\ 1}$	*S282* $x_{28\ 2}$	2,756	1,756	1,910	C28
A29	*S291* $x_{29\ 1}$	*S292* $x_{29\ 2}$	2,124	1,811	4,017	C29
A30	*S301* $x_{30\ 1}$	*S302* $x_{30\ 2}$	4,642	264	166	C30
A31	*S311* $x_{31\ 1}$	*S312* $x_{31\ 2}$	1,805	2,375	2,012	C31
A38	*S381* $x_{38\ 1}$	*S382* $x_{38\ 2}$	3,066	192	1,762	C38
A39	*S391* $x_{39\ 1}$	*S392* $x_{39\ 2}$	1,489	233	490	C39
A41	*S411* $x_{41\ 1}$	*S412* $x_{41\ 2}$	2,329	1,234	3,375	C41
A42	*S421* $x_{42\ 1}$	*S422* $x_{42\ 2}$	2,253	603	1,253	C42

TO / From	Manifold 1 (mtrs)	Manifold 2 (mtrs)	Capacity Gas(scf/stb)	Oil(BOPD)	water(BWPD)	Total
A46	$x_{46\,1}$ *S461*	$x_{46\,2}$ *S462*	2,480	77	1,165	C46
A50	$x_{50\,1}$ *S501*	$x_{50\,2}$ *S502*	2,014	678	1,682	C50
A52	$x_{52\,1}$ *S521*	$x_{52\,2}$ *S522*	1,787	713	723	C52
A53	$x_{53\,1}$ *S531*	$x_{53\,2}$ *S532*	1,893	1,243	2,356	C53
A54	$x_{54\,1}$ *S541*	$x_{54\,2}$ *S542*	2,373	254	553	C54
A55	$x_{55\,1}$ *S551*	$x_{55\,2}$ *S552*	3,385	3,469	353	C55
A56	$x_{56\,1}$ *S561*	$x_{56\,2}$ *S562*	2,000	1,500	200	C56
A57	$x_{57\,1}$ *S571*	$x_{57\,2}$ *S572*	2,374	116	1,206	C57
A58	$x_{58\,1}$ *S581*	$x_{58\,2}$ *S582*	2,960	1,268	0	C58
A60	$x_{60\,1}$ *S601*	$x_{60\,2}$ *S602*	21,103	195	6	C60
A61	$x_{61\,1}$ *S611*	$x_{61\,2}$ *S612*	3,076	316	367	C61
A62	$x_{62\,1}$ *S621*	$x_{62\,2}$ *S622*	3,101	316	367	C62
A63	$x_{63\,1}$ *S631*	$x_{63\,2}$ *S632*	5,559	83	0	C63
A64	$x_{64\,1}$ *S641*	$x_{64\,2}$ *S642*	3,204	260	3,046	C64

TO / From	Manifold 1 (mtrs)	Manifold 2 (mtrs)	Capacity Gas(scf/stb)	Oil(BOPD)	water(BWPD)	Total
A66	*S661* $x_{66\ 1}$	*S662* $x_{66\ 2}$	2,694	1,137	4,178	C66
A67	*S671* $x_{67\ 1}$	*S672* $x_{67\ 2}$	2,115	2,850	7	C67
A68	*S681* $x_{68\ 1}$	*S682* $x_{68\ 2}$	1,777	214	780	C68
A69	*S691* $x_{69\ 1}$	*S692* $x_{69\ 2}$	1425	895	4	C69
A70	*S701* $x_{70\ 1}$	*S702* $x_{70\ 2}$	2,302	1,952	3,194	C70
A71	*S711* $x_{71\ 1}$	*S712* $x_{71\ 2}$	1,570	2,961	907	C71
A75	*S751* $x_{75\ 1}$	*S752* $x_{75\ 2}$	1731	4804	1,660	C75
A78	*S781* $x_{78\ 1}$	*S782* $x_{78\ 2}$	1,067	1,269	81	C78
A80	*S801* $x_{80\ 1}$	*S802* $x_{80\ 2}$	2,046	4,224	2,989	C80
A82	*S821* $x_{82\ 1}$	*S822* $x_{82\ 2}$	1,827	311	414	C82
A83	*S831* $x_{83\ 1}$	*S832* $x_{83\ 2}$	2,208	4,907	0	C83

The linear programming in case of one manifold is represented as below:

[LP] : Minimise

$S11x_{11}+S31x_{31}+S41x_{41}+S71x_{71}+S81x_{81}+S111x_{111}+S131x_{131}+S141x_{141}+S151x_{151}+S161x_{161}+S171x_{171}+S191x_{191}+S201x_{201}+S211x_{211}+S221x_{221}+S241x_{241}+S251x_{251}+S271x_{271}+S281x_{281}+S291x_{291}+S301x_{301}+S311x_{311}+S381x_{381}+S391x_{391}+S411x_{411}+S421x_{421}+S461x_{461}+S501x_{501}+S521x_{521}+S531x_{531}+S541x_{541}+S551x_{551}+S561x_{561}+S571x_{571}+S581x_{581}+S601x_{601}+S611x_{611}+S621x_{621}+S631x_{631}+S641x_{641}+S661x_{661}+S671x_{671}+S681x_{681}+S691x_{691}+S701x_{701}+S711x_{711}+S751x_{751}+S781x_{781}+S801x_{801}+S821x_{821}+S831x_{831}$

Subjected to:-

$x_{11} \leq C_1$	$x_{191} \leq C_{19}$	$x_{381} \leq C_{38}$	$x_{571} \leq C_{57}$	$x_{701} \leq C_{70}$
$x_{31} \leq C_3$	$x_{201} \leq C_{20}$	$x_{391} \leq C_{39}$	$x_{581} \leq C_{58}$	$x_{711} \leq C_{71}$
$x_{41} \leq C_4$	$x_{211} \leq C_{21}$	$x_{411} \leq C_{41}$	$x_{601} \leq C_{60}$	$x_{751} \leq C_{75}$
$x_{71} \leq C_7$	$x_{221} \leq C_{22}$	$x_{421} \leq C_{42}$	$x_{611} \leq C_{61}$	$x_{781} \leq C_{78}$
$x_{81} \leq C_8$	$x_{241} \leq C_{24}$	$x_{461} \leq C_{46}$	$x_{621} \leq C_{62}$	$x_{801} \leq C_{80}$
$x_{111} \leq C_{11}$	$x_{251} \leq C_{25}$	$x_{501} \leq C_{50}$	$x_{631} \leq C_{63}$	$x_{821} \leq C_{82}$
$x_{131} \leq C_{13}$	$x_{271} \leq C_{27}$	$x_{521} \leq C_{52}$	$x_{641} \leq C_{64}$	$x_{831} \leq C_{83}$
$x_{141} \leq C_{14}$	$x_{281} \leq C_{28}$	$x_{531} \leq C_{53}$	$x_{661} \leq C_{66}$	
$x_{151} \leq C_{15}$	$x_{291} \leq C_{29}$	$x_{541} \leq C_{54}$	$x_{671} \leq C_{67}$	
$x_{161} \leq C_{16}$	$x_{301} \leq C_{30}$	$x_{551} \leq C_{55}$	$x_{681} \leq C_{68}$	
$x_{171} \leq C_{17}$	$x_{311} \leq C_{31}$	$x_{561} \leq C_{56}$	$x_{691} \leq C_{69}$	

$x_{11}+x_{31}+x_{41}+x_{71}+x_{81}+x_{111}+x_{131}+x_{141}+x_{151}+x_{161}+x_{171}+x_{191}+x_{201}+x_{211}+x_{221}+x_{241}+x_{251}+x_{271}+x_{281}+x_{291}+x_{301}+x_{311}+x_{381}+x_{391}+x_{411}+x_{421}+x_{461}+x_{501}+x_{521}+x_{531}+x_{541}+x_{551}+x_{561}+x_{571}+x_{581}+x_{601}+x_{611}+x_{621}+x_{631}+x_{641}+x_{661}+x_{671}+x_{681}+x_{691}+x_{701}+x_{711}+x_{751}+x_{781}+x_{801}+x_{821}+x_{831}$=349919 Bbl/D

$x_{ij} \geq 0$

Where:

i =1, 2, 3, the number of wells

j = 1 the number of manifolds

S_{ij} = the distance from the wells to the manifold.

C_i = the capacity of well i.

C_t = the total capacity of wells.

In the case of two manifolds, the linear programming is represented as below:

[LP] Minimise

$$S12x_{12}+S32x_{32}+S42x_{42}+S72x_{72}+S82x_{82}+S112x_{112}+S132x_{132}+S142x_{142}+S152x_{152}+S162x_{162}+S172x_{172}+S192x_{192}+S202x_{202}+S212x_{212}+S222x_{222}+S242x_{242}+S252x_{252}+S272x_{272}+S282x_{282}+S292x_{292}+S302x_{302}+S312x_{312}+S382x_{382}+S392x_{392}+S412x_{412}+S422x_{422}+S462x_{462}+S502x_{502}+S522x_{522}+S532x_{532}+S542x_{541}+S551x_{551}+S561x_{561}+S571x_{571}+S581x_{581}+S601x_{601}+S611x_{611}+S621x_{621}+S631x_{632}+S642x_{642}+S662x_{662}+S672x_{672}+S682x_{682}+S692x_{692}+S702x_{702}+S712x_{712}+S752x_{752}+S782x_{782}+S802x_{802}+S822x_{822}+S832x_{832}$$

Subjected to:-

$x_{12} \leq C_1$	$x_{192} \leq C_{19}$	$x_{382} \leq C_{38}$	$x_{572} \leq C_{57}$	$x_{702} \leq C_{70}$
$x_{32} \leq C_3$	$x_{202} \leq C_{20}$	$x_{392} \leq C_{39}$	$x_{582} \leq C_{58}$	$x_{712} \leq C_{71}$
$x_{42} \leq C_4$	$x_{212} \leq C_{21}$	$x_{412} \leq C_{41}$	$x_{602} \leq C_{60}$	$x_{752} \leq C_{75}$
$x_{72} \leq C_7$	$x_{222} \leq C_{22}$	$x_{422} \leq C42$	$x_{612} \leq C_{61}$	$x_{782} \leq C_{78}$
$x_{82} \leq C_8$	$x_{242} \leq C_{24}$	$x_{462} \leq C_{46}$	$x_{622} \leq C_{62}$	$x_{802} \leq C_{80}$
$x_{112} \leq C_{11}$	$x_{252} \leq C_{25}$	$x_{502} \leq C_{50}$	$x_{632} \leq C_{63}$	$x_{822} \leq C_{82}$
$x_{132} \leq C_{13}$	$x_{272} \leq C_{27}$	$x_{522} \leq C_{52}$	$x_{642} \leq C_{64}$	$x_{832} \leq C_{83}$
$x_{142} \leq C_{14}$	$x_{282} \leq C_{28}$	$x_{532} \leq C_{53}$	$x_{662} \leq C_{66}$	
$x_{152} \leq C_{15}$	$x_{292} \leq C_{29}$	$x_{542} \leq C_{54}$	$x_{672} \leq C_{67}$	
$x_{162} \leq C_{16}$	$x_{302} \leq C_{30}$	$x_{552} \leq C_{55}$	$x_{682} \leq C_{68}$	
$x_{172} \leq C_{17}$	$x_{312} \leq C_{31}$	$x_{562} \leq C_{56}$	$x_{692} \leq C_{69}$	

$$x_{12}+x_{32}+x_{42}+x_{72}+x_{82}+x_{112}+x_{132}+x_{142}+x_{152}+x_{162}+x_{172}+x_{192}+x_{202}+x_{212}+x_{222}+x_{242}+x_{252}+x_{272}+x_{282}+x_{292}+x_{302}+x_{312}+x_{382}+x_{392}+x_{412}+x_{422}+x_{462}+x_{502}+x_{522}+x_{532}+x_{542}+x_{552}+x_{562}+x_{572}+x_{582}+x_{602}+x_{612}+x_{622}+x_{632}+x_{642}+x_{662}+x_{672}+x_{682}+x_{692}+x_{702}+x_{712}+x_{752}+x_{782}+x_{802}+x_{822}+x_{832}= 349919 \text{ Bbl/d}$$

$x_{ij} \geq 0$

Where:

i =1, 2, 3, the number of wells.

j = 1 the number of manifolds.

x_{ij} = the amount of oil provided by well (i) to manifold (j).

C_i = the capacity of oil-well (i).

C_t = the total capacity of oil-wells.

S_{ij} = the distance from oil well (i) to manifold (j).

4.5 Implementation of the Proposed Mathematical Model Using Lingo/ Lindo

Solving the mathematical programme needs a large number of calculations, therefore a computer-programme will be used. This computer-programme is called Lingo/Lindo. "LINGO/ LINDO is a simple tool for utilising the power of linear and nonlinear optimization to formulate large problems concisely, solve them, and analyse the solution"(Lingo user's guide 2004).

Lingo/ Lindo is a computer-programme that allows the user to input a model formulation and provide a solution quickly. It estimates the correctness of the formulation based on the solution, and can quickly make small modifications to the formulation, and repeat the process. Lingo/ Lindo allows the grouping of the related objects together into sets.

Sets are the base of the Lingo/ Lindo modelling language; this base is the building-block of the program's most powerful capabilities. Sets are helpful in writing a series of similar constraints in a single statement, and express long complex formulas in brief. This allows you to state your largest models very quickly and easily (Schrage 2002).

To solve the linear programming-model, Lingo/ Lindo software was used, and the programme was written as a set shown below, in the following sections.

4.5.1 In the case of supply equals the demand

Supply means the total amount of crude oil which is produced from the wells and transmitted to the manifold via pipes. The demand is the amount of crude oil requested by the customer. In this case supply is equal to the demand: this means that the amount of oil produced from the wells is same as the demand for it (the oil which is requested by the customer).

The model is built as sets. It includes the TITLE, which can be used to give a short description of the LP model. The SETS: ENDSETS section of the model provides user-generated names for the basic components of the LP model; namely, constraints and variables. The number of oil-wells starts from A1 to A83, and the capacity of the wells will be written in the data-section later. The transportation-cost has to decrease in terms of the distance from the oil-wells to the manifold (M1) in case of one manifold or any number of manifolds, and the demand also will be measured at the manifold. The next section will address the objective which is the minimisation of the transportation-cost, and then the constraints in case of the oil-wells' capacity and demand. The last section is the data, which includes the wells' capacity-values, demand-values and the distances from the wells to the manifold. The output of the programme in all cases is reported in Appendix A.

```
MODEL:  Supply = Demand
SETS:

WELLS/A1,A3,A4,A7,A8,A11,A13,A14,A15,A16,A17,A19,A20,A21,A22,A24,A25
,A27,A28,A29,A30,A31,A38,A39,A41,A42,A46,A50,A52,A53,A54,A55,A56,A57
,A58,A60,A61,A62,A63,A64,A66,A67,A68,A69,A70,A71,A75,A78,A80,A82,A83
/:CAPACITY;

MANIFOLD/M1/: DEMAND;

LINKS(WELLS,MANIFOLD):DISTANCE,BARREL;

ENDSETS

MIN=@SUM (LINKS: DISTANCE*BARREL);

@FOR(MANIFOLD(J):

@SUM(WELLS(I):BARREL(I,J))>=DEMAND(J));

@FOR(WELLS(I):

@SUM(MANIFOLD(J):BARREL(I,J))<=CAPACITY(I));

DATA:

CAPACITY=6719,24321,12546,6711,10606,782,9896,2944,10951,6287,14606,
9944,8411,8646,12263,4262,11475,4311,6422,7952,5072,6192,5020,2212,6
938,4109,3722,4374,3223,5492,3180,7207,3700,3696,4228,21304,3759,378
4,5642,6510,8009,4972,2771,2324,7448,5438,8195,2417,9259,2552,7115;

DEMAND=349919;

DISTANCE=220,100,3500,55,2118,3150,6300,100,2850,2350,4100,100,4400,
60,2100,1550,1560,1300,930,1600,1000,3000,1200,1900,50,50,1300,4500,
3300,3500,1900,3700,1300,2000,5900,2000,4500,3000,4000,2200,3000,120
0,200,3700,1000,4000,900,400,3000,4000,4000;

ENDDATA
END
```

4.5.2 The Supply is Greater Than the Demand

The supply is greater than the demand. In this case the demand is decreased from 349919 Bbl/day to 330000Bbl/day, but the supply is remaining as the original data. When the model is solved via Lingo/ Lindo , the optimal solution is found, and the results will be discussed later.

```
MODEL:  Supply > Demand
SETS:

WELLS/A1,A3,A4,A7,A8,A11,A13,A14,A15,A16,A17,A19,A20,A21,A22,A24,A25
,A27,A28,A29,A30,A31,A38,A39,A41,A42,A46,A50,A52,A53,A54,A55,A56,A57
,A58,A60,A61,A62,A63,A64,A66,A67,A68,A69,A70,A71,A75,A78,A80,A82,A83
/:CAPACITY;

MANIFOLD/M1/: DEMAND;

LINKS(WELLS,MANIFOLD):DISTANCE,BARREL;

ENDSETS

MIN=@SUM(LINKS:DISTANCE*BARREL);

@FOR(MANIFOLD(J):

@SUM(WELLS(I):BARREL(I,J))>=DEMAND(J));

@FOR(WELLS(I):

@SUM(MANIFOLD(J):BARREL(I,J))<=CAPACITY(I));


DATA:

CAPACITY=6719,24321,12546,6711,10606,782,9896,2944,10951,6287,14606,
9944,8411,8646,12263,4262,11475,4311,6422,7952,5072,6192,5020,2212,6
938,4109,3722,4374,3223,5492,3180,7207,3700,3696,4228,21304,3759,378
4,5642,6510,8009,4972,2771,2324,7448,5438,8195,2417,9259,2552,7115;

DEMAND=330000;

DISTANCE=220,100,3500,55,2118,3150,6300,100,2850,2350,4100,100,4400,
60,2100,1550,1560,1300,930,1600,1000,3000,1200,1900,50,50,1300,4500,
3300,3500,1900,3700,1300,2000,5900,2000,4500,3000,4000,2200,3000,120
0,200,3700,1000,4000,900,400,3000,4000,4000;

ENDDATA
END
```

4.5.3 The Supply is Less Than the Demand

The amount of crude oil from the wells (supply) is less than the demand. This happens when the value of the demand in the original data was increased from 349919 Bbl/day to 750000 Bbl/day to check different scenarios. The results show that no feasible solution was found and the results will be discussed later.

```
MODEL: Supply< Demand
SETS:

WELLS/A1,A3,A4,A7,A8,A11,A13,A14,A15,A16,A17,A19,A20,A21,A22,A24,A25
,A27,A28,A29,A30,A31,A38,A39,A41,A42,A46,A50,A52,A53,A54,A55,A56,A57
,A58,A60,A61,A62,A63,A64,A66,A67,A68,A69,A70,A71,A75,A78,A80,A82,A83
/:CAPACITY;

MANIFOLD/M1/:DEMAND;

LINKS(WELLS,MANIFOLD):DISTANCE,BARREL;

ENDSETS

MIN=@SUM(LINKS:DISTANCE*BARREL);

@FOR(MANIFOLD(J):

@SUM(WELLS(I):BARREL(I,J))>=DEMAND(J));

@FOR(WELLS(I):

@SUM(MANIFOLD(J):BARREL(I,J))<=CAPACITY(I));

DATA:

CAPACITY=6719,24321,12546,6711,10606,782,9896,2944,10951,6287,14606,
9944,8411,8646,12263,4262,11475,4311,6422,7952,5072,6192,5020,2212,6
938,4109,3722,4374,3223,5492,3180,7207,3700,3696,4228,21304,3759,378
4,5642,6510,8009,4972,2771,2324,7448,5438,8195,2417,9259,2552,7115;

DEMAND=750000;

DISTANCE=220,100,3500,55,2118,3150,6300,100,2850,2350,4100,100,4400,
60,2100,1550,1560,1300,930,1600,1000,3000,1200,1900,50,50,1300,4500,
3300,3500,1900,3700,1300,2000,5900,2000,4500,3000,4000,2200,3000,120
0,200,3700,1000,4000,900,400,3000,4000,4000;

ENDDATA
END
```

4.5.4 Demand is Greater than the Supply (Dummy Solution)

The transportation-model must be balanced, that means that the supply equals the demand. But in the case where the model is unbalanced, it is always increased with a dummy source or dummy destination to make a balance between the supply and the demand (Taha 2003).

In this case, demand is greater than the supply, because the demand is 360000 Bbl/day and the supply is 3491999 Bbl/day. One more well is introduced (A84); it is called a dummy well with a capacity of 10081 Bbl/day to make a balance between the supply and the demand. When the model was solved via Lingo/ Lindo, the optimal solution was found.

```
MODEL: Demand > Supply
SETS:

WELLS/A1,A3,A4,A7,A8,A11,A13,A14,A15,A16,A17,A19,A20,A21,A22,A24,A25
,A27,A28,A29,A30,A31,A38,A39,A41,A42,A46,A50,A52,A53,A54,A55,A56,A57
,A58,A60,A61,A62,A63,A64,A66,A67,A68,A69,A70,A71,A75,A78,A80,A82,A83
,A84/:CAPACITY;

MANIFOLD/M1/:DEMAND;

LINKS(WELLS,MANIFOLD):DISTANCE,BARREL;

ENDSETS

MIN=@SUM(LINKS:DISTANCE*BARREL);

@FOR(MANIFOLD(J):

@SUM(WELLS(I):BARREL(I,J))>=DEMAND(J));

@FOR(WELLS(I):

@SUM(MANIFOLD(J):BARREL(I,J))<=CAPACITY(I));

DATA:

CAPACITY=6719,24321,12546,6711,10606,782,9896,2944,10951,6287,14606,
9944,8411,8646,12263,4262,11475,4311,6422,7952,5072,6192,5020,2212,6
938,4109,3722,4374,3223,5492,3180,7207,3700,3696,4228,21304,3759,378
4,5642,6510,8009,4972,2771,2324,7448,5438,8195,2417,9259,2552,
7115,10081;

DEMAND=360000;

DISTANCE=220,100,3500,55,2118,3150,6300,100,2850,2350,4100,100,4400,
60,2100,1550,1560,1300,930,1600,1000,3000,1200,1900,50,50,1300,4500,
3300,3500,1900,3700,1300,2000,5900,2000,4500,3000,4000,2200,3000,120
0,200,3700,1000,4000,900,400,3000,4000,4000,0;

ENDDATA
END
```

4.5.5 The Supply is Greater than the Demand (Dummy Solution)

In this case the supply is greater than demand, because the supply is 3491999 Bbl/day and the demand is 340000 Bbl/day. Dummy demand is added, which will be the difference between the supply and demand. This is 9919 Bbl/day used to achieve the balance between the supply and demand. The model solved by Lingo/ Lindo and optimal solution was found.

```
MODEL: Supply > Demand
SETS
WELLS/A1,A3,A4,A7,A8,A11,A13,A14,A15,A16,A17,A19,A20,A21,A22,A24,A25
,A27,A28,A29,A30,A31,A38,A39,A41,A42,A46,A50,A52,A53,A54,A55,A56,A57
,A58,A60,A61,A62,A63,A64,A66,A67,A68,A69,A70,A71,A75,A78,A80,A82,A83
/:CAPACITY;

MANIFOLD/M1,M2/:DEMAND;

LINKS(WELLS,MANIFOLD):DISTANCE,BARREL;

ENDSETS

MIN=@SUM(LINKS:DISTANCE*BARREL);

@FOR(MANIFOLD(J):

@SUM(WELLS(I):BARREL(I,J))>=DEMAND(J));

@FOR(WELLS(I):

@SUM(MANIFOLD(J):BARREL(I,J))<=CAPACITY(I));

DATA:
CAPACITY=6719,24321,12546,6711,10606,782,9896,2944,10951,6287,14606,
9944,8411,8646,12263,4262,11475,4311,6422,7952,5072,6192,5020,2212,6
938,4109,3722,4374,3223,5492,3180,7207,3700,3696,4228,21304,3759,378
4,5642,6510,8009,4972,2771,2324,7448,5438,8195,2417,9259,2552,7115;

DEMAND=340000,9919;

DISTANCE=220,0,100,0,3500,0,55,0,2118,0,3150,0,6300,0,100,0,2850,0,2
350,0,4100,0,100,0,4400,0,60,0,2100,0,1550,0,1560,0,1300,0,930,0,160
0,0,1000,0,3000,0,1200,0,1900,0,50,0,50,0,1300,0,4500,0,3300,0,3500,
0,1900,0,3700,0,1300,0,2000,0,5900,0,2000,0,4500,0,3000,0,4000,0,220
0,0,3000,0,1200,0,200,0,3700,0,1000,0,4000,0,900,0,400,0,3000,0,4000
,0,4000,0;

ENDDATA
END
```

4.6 Results Analysis and Discussion

In this study mathematical programming was applied to reduce the transportation-cost of crude oil from the wells to the manifold in terms of the distance between the wells and the manifolds.

The results which are obtained by using linear programming are very practical in the improvement of decision-making, because it provides the freedom of selection between a massive number of wells with different capacities and at different distances, and this helps in the decision-making process and leads to a decrease in the missing time and an increase in the productivity of the field. Different scenarios were applied to examine the programme in different cases. Some of these cases give the optimum solution and some of them do not; this depends on the amount of oil which is supplied to the manifold and also on the customer demand. When the results didn't give the optimum solution, a dummy solution was applied to make a balance between the supply and the demand. These different cases are presented below:-

Case 1

The capacity of wells (supply) is equal to the demand, and the constraint on the demand is that the amount of oil produced from wells to the manifold is >= the demand at the manifold. The capacity constraint is that the amount of oil produced from every well to the manifold is <= the capacity of every well at the manifold.
In this case the optimal solution was found, and the slack or surplus values were non zero because the constraints are non-binding constraints. There are no changes in the capacity of the wells because the supply is equal to the demand, and the results are shown in figure1 in Appendix A.

In this Appendix there are five sections: section (1) represents the capacity of the oil-wells, section (2) shows the demand, section (3) displays the distance between wells and the manifolds, the amount of crude oil from wells to the manifold is shown in section (4), and section (5) demonstrates the slack or surplus.

Case 2

When the supply is greater than demand, an optimal solution is also found. But in this case we note that some of oil-wells are closed; we can see that in wells number A13, A50, and A5. These wells are the farthest from the manifold, and the production of some wells is decreased which are a long distance from the manifold, We can see this in well number A61 where the production decreased from 3759 Bbl/d to 2338 Bbl/d to fulfil the demand at the manifold. The results are shown in figure 2, Appendix A. In this case the cost of transportation is decreased (in terms of distance). We can note this in the objective value when the supply is equal the demand. The objective value was 0.7642677E+09, and when the supply is greater than the demand, the objective value is 0.6509002E+09; that means that the distance is optimum and the distance is represented in the cost of transportation.

4.6.1 Introduction of Dummy Supply and Demand

When the demand is greater than the supply, no feasible solution is found. The result is shown in figure 3, Appendix A, and in this case a dummy should be used as shown below:

Case 3 Dummy Supply

In this case where demand is greater than the supply, a dummy supply with capacity of 10081 Bbl/D is added to balance the transportation model. In this case the transportation-cost from the dummy well to the manifold is zero because the well does not exist. The Lingo output of the dummy solution is shown in figure 4 Appendix A.

Case 4 Dummy Demand

However, in the case where the supply is greater than the demand, a dummy manifold with capacity of 9919 Bbl/D is added to balance the transportation model. In this case the transportation-cost from the wells to the dummy manifold is zero because the manifold does not exist (Taha, 2003). The Lingo output of dummy solution is shown in figure 5 Appendix A.

4.7 Conclusion

In this chapter the mathematical technique was proposed and applied using a real case, the oil-wells' problems were modelled by using linear programming to solve the problem of crude oil transportation and the model was solved by Lindo/ Lingo software.

The problem was studied considering different scenarios and deciding on the most suitable operational policy.

The model which was developed by Lindo/ Lingo software gives flexibility to select the most suitable operational policy for the oil wells. This depends on the oil-wells' capacity, distance from the oil-wells to the manifold and the demand requested from the customers.

In the case of the demand being greater than supply, or when the supply is greater than demand, the dummy solution was applied in both cases to make the balance between the supply and the demand.

As can be seen from the results, the cost (in terms of distance) has been minimised. This was clear when the supply was greater than the demand: in this case the models minimise the travelling-distance by avoiding the farthest wells from the manifold. (See Case 2).

It is anticipated that the proposed mathematical model will provide a systematic tool for the practitioners in the company to decide on the most appropriate policy in order to minimise the oil transportation-cost for the wells to the manifold.

The next chapter will be about the modelling and analysis of the oil separation area. It will give full information about the simulation of the separation area, data and different layout-diagrams which represent the separation area and the model.

Chapter 5

Modelling and Analysis of the Oil Separation Area

5.1 Introduction

The optimisation of the crude oil transportation-cost from the oil-wells to the manifold was discussed in the previous chapter.

This chapter will bring out how to model the systems, what is to be considered in the simulation model as the input, experimental factors and outputs, how to gather and analyse the data, comments on the models built, and the verification and validation of the proposed models.

5.2 Conceptual Model

The way that an operations-manager looks at the systems and processes is a lot different from a simulation-modeller. If the operations are to be modelled and simulated, the manager wants the whole operation including all the details to be modelled and shown. Nonetheless, it is not always possible to model and simulate every detail exactly the same as in real system. The difficulties in obtaining the data required for the real system's design are the main reason for this problem. Besides, the modeller might not have enough knowledge and experience in the systems to be modelled. When dealing with a simple system, it is easy for the modeller to understand and drafted out some kind of drawings to represent the real system, but when it comes to a large and complex system, the modeller might be in perplexity staring at the whole system. This, however, could be sorted out by spending some time considering what needs to be modelled and what data should be included in the model. Therefore, it is important to have a conceptual model set up to combine all the objectives of simulation, inputs, outputs and assumptions made to simplify the model for better understanding of the types of system to be modelled and the level of modelling (how detailed the model should be). Robinson (2004) explained that "the conceptual model is a non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model."

5.2.1 Objectives of the Simulation Modelling

As mentioned in section 1.2, the aims and objectives of this project were to carry out the design and analysis of the oil production systems through simulation-modelling. The number of production lines, the capacity of separator (SP), oil quality and arrival-rate of the crude oil were to be taken as the experimental factors in the simulation.

Crude oil separation processes have a lot of interactions with the characteristics and some other explicit factors which affect the process-effectiveness. A process-flow diagram will be drawn to show the process-flow of the crude oil separation-processes for conceptual model-building.

5.2.2 Process Flowcharts

Figure 5.1 shows the flowchart from the very beginning of the separation-processes where the crude oil flows from manifold to the stage one (S1) horizontal SP which was converted from the layout-diagram in figure 5.2 collected from Eni (Libya). This process flow-chart is one of the ways for representing the conceptual model and is very important to the development of a computer-simulation model.

Prior to the flow from the manifold to S1-SP, the data of oil-demand at the end of the production-line determines the flow-rate for crude oil arrival to S1-SP. When the crude oil arrives at the S1-SP, it is flushed at 700 psi high pressure into the SP. In here the crude oil will be separated into gas and liquid which consists of water and other liquid compounds. The gas will flow to the gas-plant and the liquid separated will be transferred to S2 horizontal SP. The flow-pressure changes from 700 psi to 350 psi for this stage. The crude oil is now separated into gas, oil and water. Again, the gas flows to the gas plant, and water flows to the water-treatment reservoir since it still contains oil. The oil is not fully separated from the other gaseous and liquid compounds at this stage. Therefore, the oil will be transferred from S2 to S3 horizontal SP for further processing. The oil is flushed at lower pressure, 30 psi, and separated into gas, oil and water. In the real system, there might be a little water left in the oil at this stage depending on the quality of the crude oil. However, it is assumed in this model that the water is fully separated at S3. Later, the oil flows to S4-SP which is called a vertical separator (VSP) or gas boot. This VSP is used to separate the minor gas left in the oil at normal atmospheric pressure, one atmosphere.

After this stage, the gas is fully separated and the oil is now ready to be transferred to the delivery-tank or storage-tank. There are two delivery storage-tanks at capacity of 30,660 barrels and two other storage tanks at capacity of 183,500 barrels. If anything happens with the production-lines or delivery of the final product in this separation site, the oil will be transferred to the storage-tanks if delivery storage-tanks are full. However, the final oil-output here is not the final product which can be used in vehicles and needs further refining-processes which are not covered in this thesis. The oil is later transferred to the Oil Centre Z.O.C INTISAR for storage and is ready for the next processes or delivery to port for export.

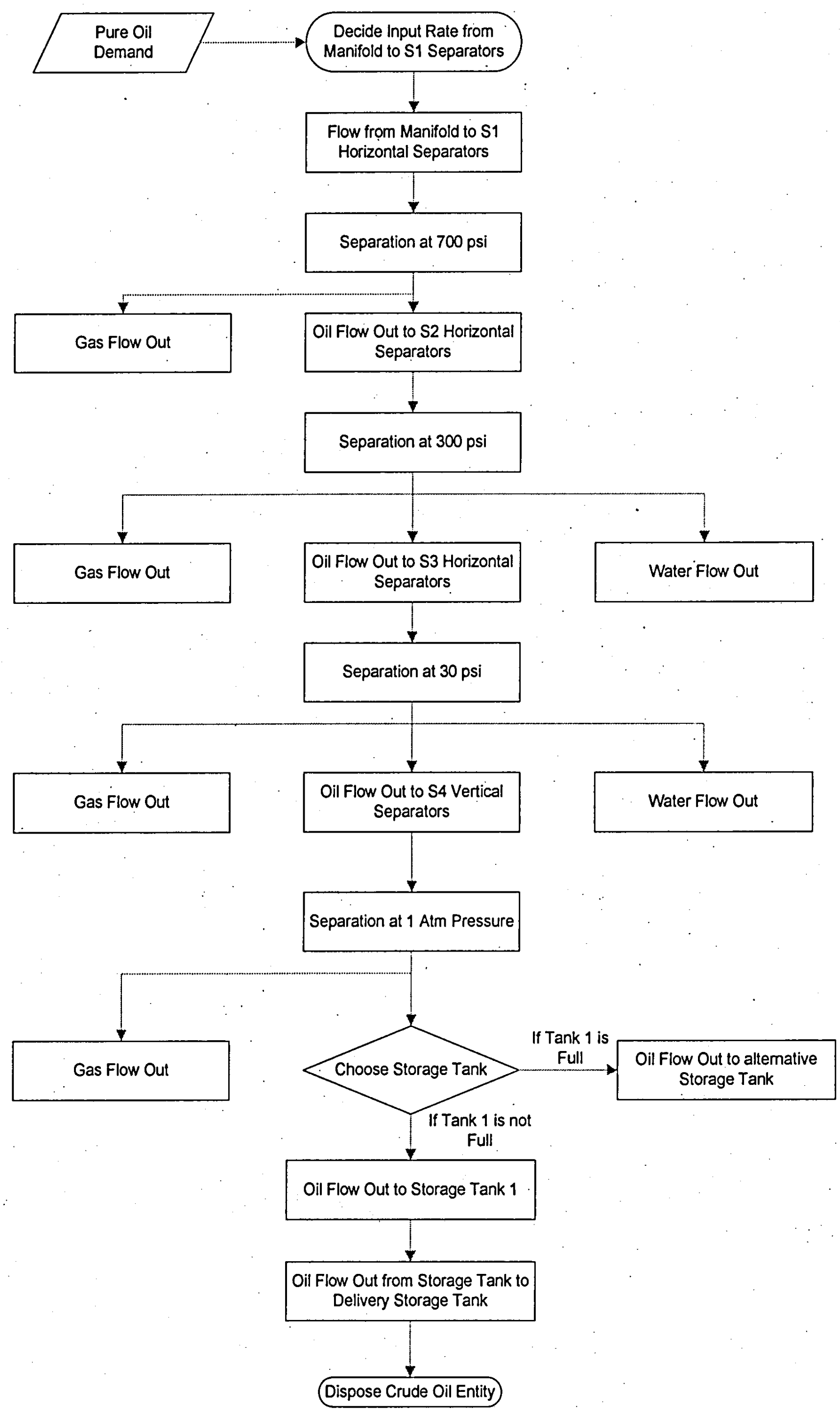


Figure 5.1 Process Flow-chart of Crude Oil Separation

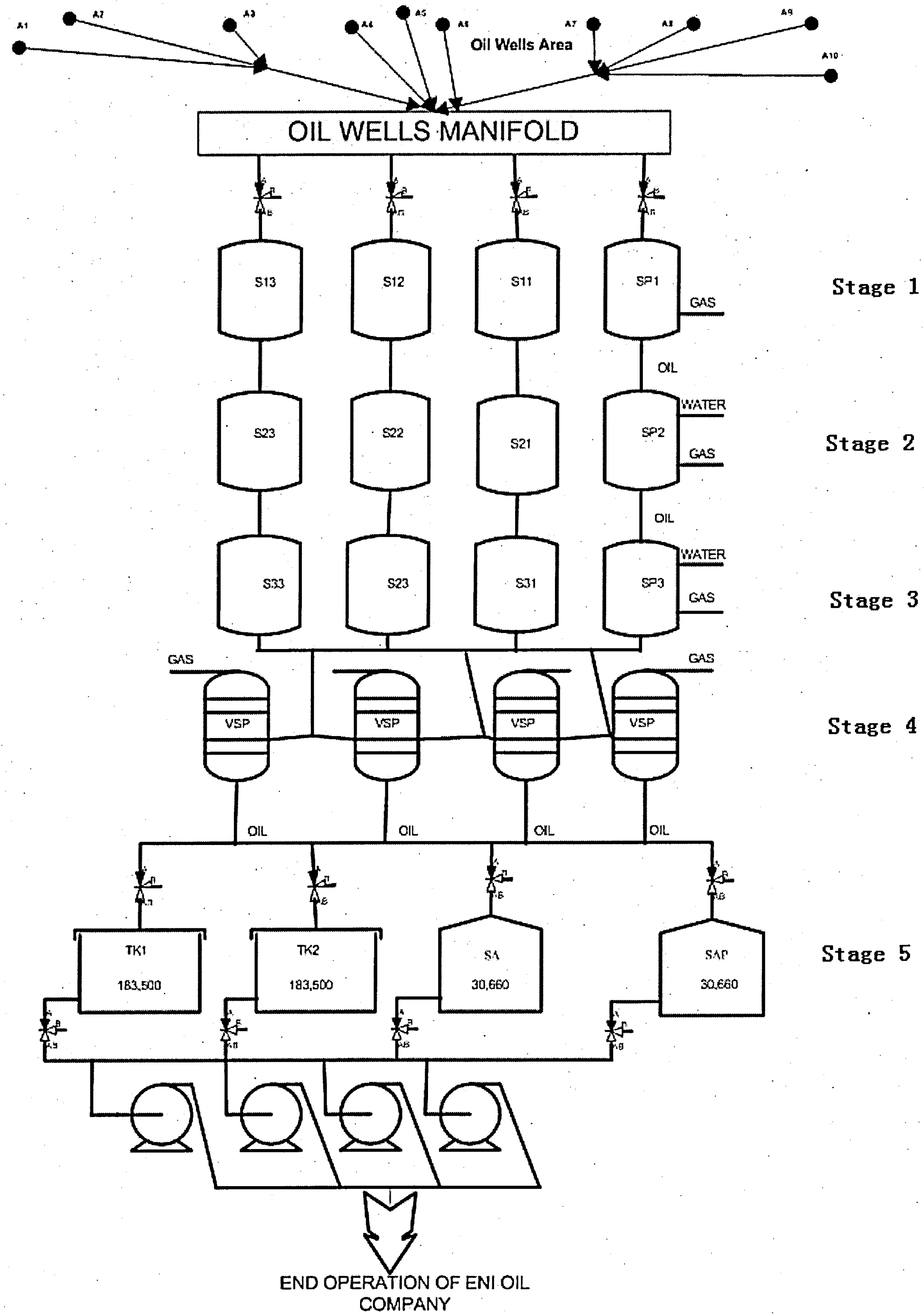


Figure 5.2 Crude Oil Separation-process Layout Diagram

5.3 Data Collection and Assumptions

Data are most important in model-building which normally consists of numeric values. However, according to Robinson (2004), the data can be split into three types which are "preliminary or contextual data, data for model-realisation, and data for model-validation". Preliminary data is the data used for understanding and building the conceptual model, for example the layout-diagram of the oil-production facility, and the diagram of the separation-process and equipment. The data for the model-realisation are those which are used for developing the computer-model, for example the arrival-rate of crude oil, the daily demand for oil, the processing-rules for separation, and descriptions of the separated product-types. The data required for model-validation are those data used for comparison with the results from models. This section will discuss the data provided and how they were used in the model-building.

5.3.1 Input and Experimental Factors

In any system, there will always be inputs as the object being processed. Things that are related to the object, showing the characteristics of the object and controlling the object are called experimental factors. In this research, the crude oil is the object being processed. The experimental factors are the crude oil arrival-rate which determines and controls the quantity of crude oil that flows into the separation system. The amount of water in the crude oil determines the quality of the crude oil, the less water contents means the more oil and gas output as a result. The number of production-lines is a factor which affects the amount of crude oil to be processed and the amount of oil produced. The data for the arrival-rate of crude oil, the amount of water-content in the crude oil, the capacity of SP and number of production lines are listed in table 5.1 and table 5.2.

5.3.2 Outputs

The outputs from the separation-process are gas, oil, and water. The output-rate of gas and water from each stage can be found in table 5.1. The output-rate of the oil from each stage will be calculated in section 5.3.3. However, the final output-rate of oil is provided in the table 5.3.

5.3.3 Assumptions and Model Simplification

Assumptions are made due to the scarcity of the data required and understanding of the detailed design of the internet-design of the equipment used. The factors that affect the separation-process are the density of flow, viscosity, amount of existing impurities, amount of water, pressure, temperature, diameter of pipes, etc. Different pipes with different types of materials are able to support different levels of flow-pressure, temperature and amount of flow per unit-time.

Due to the complexities and lack of data related to these factors, only the flow-rate, quality of crude oil and number of production-lines were taken into account as input and experimental factors in this model design. In this project, the maximum flow-rate that the pipes are able to support was assumed to be 21734.47 bbl/min. This assumption was decided base on the total amount of water, gas and oil in the final output from the separator. Even this figure has been assumed but in fact is quite related to some real data collected from the filed understudy as shown in table 5.1.

The manifold which consists of various pipes from the oil wells to the production area considered as one big tank or one big reservoir in the simulation-model, because the modeller have difficulty to represent this very complex area in the model.

The initial level of the SP was set to 25,000 barrels for the separators in Stage 1 and Stage 4 because the separators capacity is 50,000 barrels and the oil in these two stages will start to be separated when the level of the oil arrive to 25,000 barrels. The separators capacity for Stage 2 and Stage 3 is 100,000 barrels, so 50,000 barrels were set as initial level for these two stages 2 and 3 for same reason as the separation process will start when the oil level arrive to 50,000 barrels. Since the current operating-system was established and operating with oil inside. Although the initial level had been set to 50 percent of their capacity, the experiment for the empty initial level could be simulated since the model had a Hold module used to wait for the SP to exceed 50 percent of SP capacity.

"It is almost impossible to understand and isolate all the interrelationships in a real-world system, and one is forced to trade off reality, generality, and accuracy for simplicity. Therefore the models we build usually include only a subset of the variables and interrelationships of the original system" (Neelamkavil, 1987). The process-time and settling-process inside the SP were ignored and considered to be included in the term 'flow-rate'. The term 'flow-rate' means the amount of liquid, or gas, per minute, per hour or per day. However, the minimum level for the weir in the SP was considered in the model so that the oil had to fill up to a certain level to allow it to overflow into the weir and be transferred to the next stage. The ratio for gas, oil and water to be separated from the crude oil at each stage differed; it was calculated by assumption and added onto the data collected. The calculation for these ratios will be shown in table 5.4 by using the Excel file application.

Table 5.1 Data Provided

Equipment	Capacity (barrels)
4 x S1-SP	50,000
4 x S2-SP	100,000
4 x S3-SP	100,000
2 x S4-SP	50,000
2 x Delivery Tank	30,660
2 x Storage Tank	183,500
Inputs/Outputs	**Amount / Day**
Input to S1-SP	31,297,639 bbl
Gas Output from S1-SP	108 MMscf
Gas Output from S2-SP	53 MMscf
Gas Output from S3-SP	11.5 MMscf
Gas Output from S4-SP	1.5 MMscf
Water Output from S1-SP	-
Water Output from S2-SP	20,000 bbl
Water Output from S3-SP	8,900 bbl
Water Output from S4-SP	-
Oil Output from S4-SP	100,000 bbl
Production Layout	**Value**
Number of Production Lines	4

Table 5.2 Component list for the model

Components	**Details**
Inputs and Experimental Factors	1. Crude oil arrival rate 2. Number of production line 3. Quality of crude oil (water contents) 4. Capacity of SP
Outputs	1. Flow rates of oil, water and gas from different SP
Assumptions	1. Oil ratio 2. Gas ratio 3. Water ratio 4. Max flow rate that the pipes can support 5. Height and level of oil weir 6. Oil existed in the separators
Simplifications	1. Flow pressure, viscosity, material and diameter of pipes, internal separation process time and settling process excluded, 2. Manifold were simplified as one big pipe 3. Piping from the vertical SP to delivery and storage tanks were simplified to reduce the complexity of model

Calculation:

Table 5.3 Calculation of the oil output-rate at each stage

Crude Oil Arrival-Rate	= 31,297,639 (bbl/day)
Water Output-rate 2 from S2	= 20,000 (bbl/day)
Water Output-rate 3 from S3	= 8,900 (bbl/day)
Gas Output-rate 1 from S1	= 108 (MMscf/day) = 108 * 1,000,000 * 1 / 5.6146 (bbl/day) = 19,235,564.42 (bbl/day) *1 Barrel (U.S Petrol) = 1/5.6146 cubic feet (Coulson and Richardson, 1999)*
Gas Output-rate 2 from S2	= 53 (MMscf/day) = 53 * 1,000,000 * 1 / 5.6146 (bbl/day) = 9,439,675.13 (bbl/day)
Gas Output-rate 3 from S3	= 12 (MMscf/day) = 12 * 1,000,000 * 1 / 5.6146 (bbl/day) = 2,137,284.9357 (bbl/day)
Gas Output-rate 4 from S4	= 2 (MMscf/day) = 2 * 1,000,000 * 1 / 5.6146 (bbl/day) = 356,215.155951 (bbl/day)
∴ Oil Output-rate 1 from S1	= *Crude Oil Arrival Rate – Gas Output Rate Stage 1* = 31,297,639 – 19,235,564.42 ≈ 12,062,074.578670 (bbl/day)
∴ Oil Output-rate 2 from S2	= *Oil Output Rate 1 – Gas Output Rate 2 – Water Output Rate 2* = 12,062,074.578670 – 9,439,675.132690 – 20,000 ≈ 2,602,399.445980 (bbl/day)
∴ Oil Output-rate 3 from S3	= *Oil Output Rate 2 – Gas Output Rate 3 – Water Output Rate 3* = 2,602,399.445980 – 2,137,284.935703 – 8,900 ≈ 456,214.510277 (bbl/day)
∴ Oil Output-rate 4 from S4	= *Oil Output Rate 3 – Gas Output Rate 4 – Water Output Rate 4* = 456,214.510277 – 359,214.155951 - 0 ≈ 100,000.35 (bbl/day)

By referring to the table 5.1, the crude oil arrival-rate, gas and water output-rate from each stage were given. However, the oil output-rate for each stage remained unknown and therefore the calculation in table 5.3 helped to assume the estimated oil output-rate depending on the gas and water output-rates given. In an ideal case, the input to the SP should be equal to the total output from the SP. Therefore, the oil output-rate could be calculated by deducting the gas and water output-rate from the total input. The crude oil arrival-rate was equivalent to the input of stage-one S1-SP, whilst the oil output-rate 1 from S1-SP was considered as the input of the following stage.

In table 5.4, the ratios were calculated by dividing each of the gas, oil and water outputs by their total input at that particular stage. The oil output of the current stage would be the input of following stage as explained before. All the data and results from the calculations in the table above would be used in the model-building. Besides, one thing should be noted in the amendment of these ratios throughout the experiments: the water-content would be changed and these units which were reduced or increased would be replaced by gas and oil resulting in the increase of gas and oil while the water reduced.

Table 5.4 Calculation of the Gas, Oil and Water Ratio

	Formula	Value
Oil Ratio 1	*= Oil Output-rate 1 / Crude Oil Arrival-rate*	0.38540
Oil Ratio 2	*= Oil Output-rate 2 / Oil Output-rate 1*	0.21575
Oil Ratio 3	*= Oil Output-rate 3 / Oil Output-rate 2*	0.17531
Oil Ratio 4	*= Oil Output-rate 4 / Oil Output-rate 3*	0.21920
Gas Ratio 1	*= Gas Output-rate 1 / Crude Oil Arrival-rate*	0.61460
Gas Ratio 2	*= Gas Output-rate 2 / Oil Output-rate 1*	0.78259
Gas Ratio 3	*= Gas Output-rate 3 / Oil Output-rate 2*	0.82127
Gas Ratio 4	*= Gas Output-rate 4 / Oil Output-rate 3*	0.78080
Water Ratio 2	*= Water Output-rate 2 / Oil Output-rate 1*	0.00166
Water Ratio 3	*= Water Output-rate 3 / Oil Output-rate 2*	0.00342

5.4 Model-building and Descriptions

Before starting the model-building, there was a need to identify what types of model was suitable to the crude oil separation-process. The crude oil separation-process was mainly considered as a continuous system although little discrete events occurred. The continuous flow of liquid and gas changed according to time and was recognised as a continuous event as well as a dynamic system, while the process of waiting for a signal was considered as a discrete event. Since the input determined the output produced at the end of the production line, it could be seen as a deterministic system.

Arena Templates' Panels Used

Arena has two types of templates which are the old and new templates. The work carried out in this research was using the new templates with more advanced and integrated modules. The templates' panels and modules used in the models are shown below:

Table 5.5 Flow Process modules used

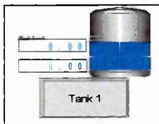
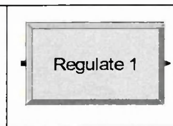
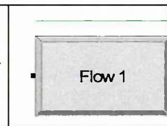
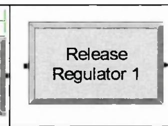
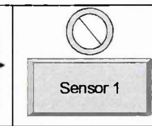
						
Tank Module	Seize Regulator Module	Regulate Module	Flow Module	Release Regulator Module	Sensor Module	Regulator Set Spreadsheet Module

Table 5.6 Basic Process modules used

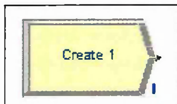
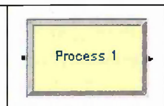
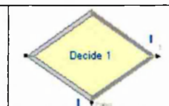
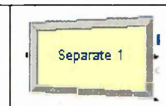
						
Create Module	Assign Module	Process Module	Decide Module	Separate Module	Dispose Module	Variable Spreadsheet Module

Table 5.7 Advanced Process module used


Delay Module

Table 5.8 Block used


Duplicate Block

The whole model for the crude oil separation was firstly drawn by using the flow-chart which was elaborated from figure 5.1 and split into different sectional models as shown in figure 5.3 to figure 5.10. This step was important to sketch out details to be included in the model-building when using Arena. The more detailed the process flow-charts were, the easier it was when coming to the model-building and the less the rework needed. Therefore, efforts and time spent at this stage to plan out the whole model were worthwhile compared to the time spent to redesign the process. However, the model-description in this chapter focused on explaining first production-lines since most of them were doing the same thing; the only difference was the name used for different SP. For details regarding the model logic drawn in Arena, please refer to Appendix B.

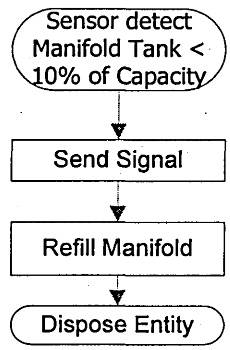


Figure 5.3 ARENA Flow-chart of Manifold Refill

5.4.1 Tank Modules

The models started by initiating the number of tanks to represent the SP, manifolds and storage-tanks which are the 21 tank modules as shown in the figure 8 of Appendix B. One of them represented the manifold; nine others represented the horizontal SP in S1 to S3; four of them represented the four VSP in S4; two represented the delivery-tanks and the last two represented the two storage-tanks. The reason to start from the tank modules was because anything showing the liquid or gaseous flow was controlled by the regulator which could only be set in the tank modules.

In the manifold tank module, one input-regulator and four output-regulators were initialised with zero regulator rates, since the rates were decided and set along the model at each stage. All the S1-SP were initialised with one input-regulator and two output-regulators for gas and oil flow-out. These processes were carried out similarly for S2-SP, S3-SP and S4-SP which had an extra output-regulator for water flow-out added to them. For the delivery-tanks and storage-tanks, four input-regulators and three output-regulators were initialised to allow the flow-in from four different production-lines and output for oil, gas and water.

5.4.2 Separation-process from Manifold to Stage 1 (S1) Separators (SP)

In the separation-process from the manifold to S1-SP, the first step was to create four different types of entity at time zero, named Crude Oil 1, Crude Oil 2, Crude Oil 3 and Crude Oil 4. These entities were used to trigger the crude oil separation-process or to activate the production-line, not as objects to be processed, and later assigned with a different tank index at the next step. Crude Oil 1 entity was assigned with attribute Stage1TankIndex and ManifoldTankIndex equal to '1', the other three entities were assigned with attributes according to their name with 2, 3 and 4.

The 'seize manifold and S1 input regulators' module seized the manifold output-regulators and the input-regulators of S1-SP. If the separator had only one entity, it might not be necessary to use this module, but four entities were used in this stage and it was necessary for the system to understand which entity was occupying which regulator. This decision could be made by choosing the regulator according to the tank index priory set. Before the entities moved into the Regulate module, a variable named T1Regs was assigned to the entity which passed through with value equal to 'T1Regs + 1'. It was used to increase the number of regulators in use.

The flow-rate of the transfer between the manifold and S1-SP was adjusted by the 'regulate S1 input regulators' module. There was one variable set with four different values in the 'variable spreadsheet' module. This was known as the input-rate which could be changed in the Utilisation interface form when the simulation was run. Four values of input-rate were used as four different levels of input-rate experimental factor, 21734.47 bbl/min, 10867.24 bbl/min, 7244.82 bbl/min, and 5433.62 bbl/min. Each of these input-rates contributed a different utilisation to SP which was 72 percent, 61 percent, 57 percent and 55 percent. In the Regulate module, the expression 'Stage1RegRate(Max(1, T1Regs))' was set to all of the output- and input-regulators at this stage. This expression allowed the system to choose the rates according to the number of production-lines activated. If there was only one line activated, the flow-rate would be adjusted to 21734.47 bbl/min, 10867.24 bbl/min for two lines, 7244.82 bbl/min for three lines or 5433.62 bbl/min for four lines. This function was used for the production of 100,000 bbl/day of oil. The four values could be identical in other cases for experiments on how the input-rate affected the output, which will be discussed later in Chapter 6. The input regulator-rates for S1-SP were set equal to the output regulator-rate of the manifold divided by 'varS1DivRatio' with an initial value of '1'. 'varS1DivRatio' is a variable used to control the regulator-rate; a new value could be assigned to change the variable.

S1 Input Rate = Manifold Output Rate / varS1DivRatio

The next process was assigning the attribute for separator-level condition-checking in the next Decide module. The required SP level had to be between 25,000 barrels and 75 percent of the SP capacity to get through to the next step. If the level was less than 25,000 barrels, or more than the SP capacity, the entity would be directed to the Dispose module for elimination. If the level was between 75 percent and maximum capacity, the entity would be directed to a Delay module waiting for the level to be reduced to the required level at point 'A' in figure 5.4.

Starting from point A, the entity would go through a series of processes to check if the level of SP exceeded the required level or was less than the required level in order to change the crude oil input-rate as a solution. If the current SP level exceeded the required level, the entity would be entered on the line which was used for reducing the input regulator-rate by increasing the variable 'varS1DivRatio' value. This line also reduced that variable if the SP level was less than the required level. The entity moved out of the system if neither of the cases mentioned above happened. Before the 'varS1DivRatio' was changed, leaving the system meant the number of regulators in use was reduced, therefore the regulator-rates had to be updated according to the number of entities left, and higher input-rates were assigned to the regulators in use to maintain the production throughput. The entity was then released so it could be seized again when it looped back to the Seize module for the next process cycle.

Back to the first Decide module: 'If SP Level < Initial Level or in Utilisation Level'. The entity sent out by the initial level met was assigned with another attribute for the

Decide module to check if the current regulator-rate provided the input that fitted into the allowable level. The equation for calculating the utilisation is:

*Utilisation = [(Time * Input Rate + SP Initial Level) / SP Capacity * 100]*

Where:

Time: time used in simulation, when creating the entity (in the creating module).

Input rate: experimental design value.

SP initial level: 25000 bbl.

SP capacity: the experimental design value.

If the condition was met, the flow from manifold to SP would be started until a signal was sent from the sensor, after which the flow-process was terminated. The number of regulators used was updated and the entity entered the 'Check Manifold and SP Index' in order to loop back the entity according to its index-number. If an error occurred with the index-number, the entity was disposed of. The two sensors acted as the level-controller, detecting if the level dropped below the minimum required level or exceeded the maximum required level. A signal was sent to all the Flow Modules in S1 since they were all having the same procedures and processes, unless stated differently. The entity created would loop back and forward until the run-time ended or disposed of if errors occurred.

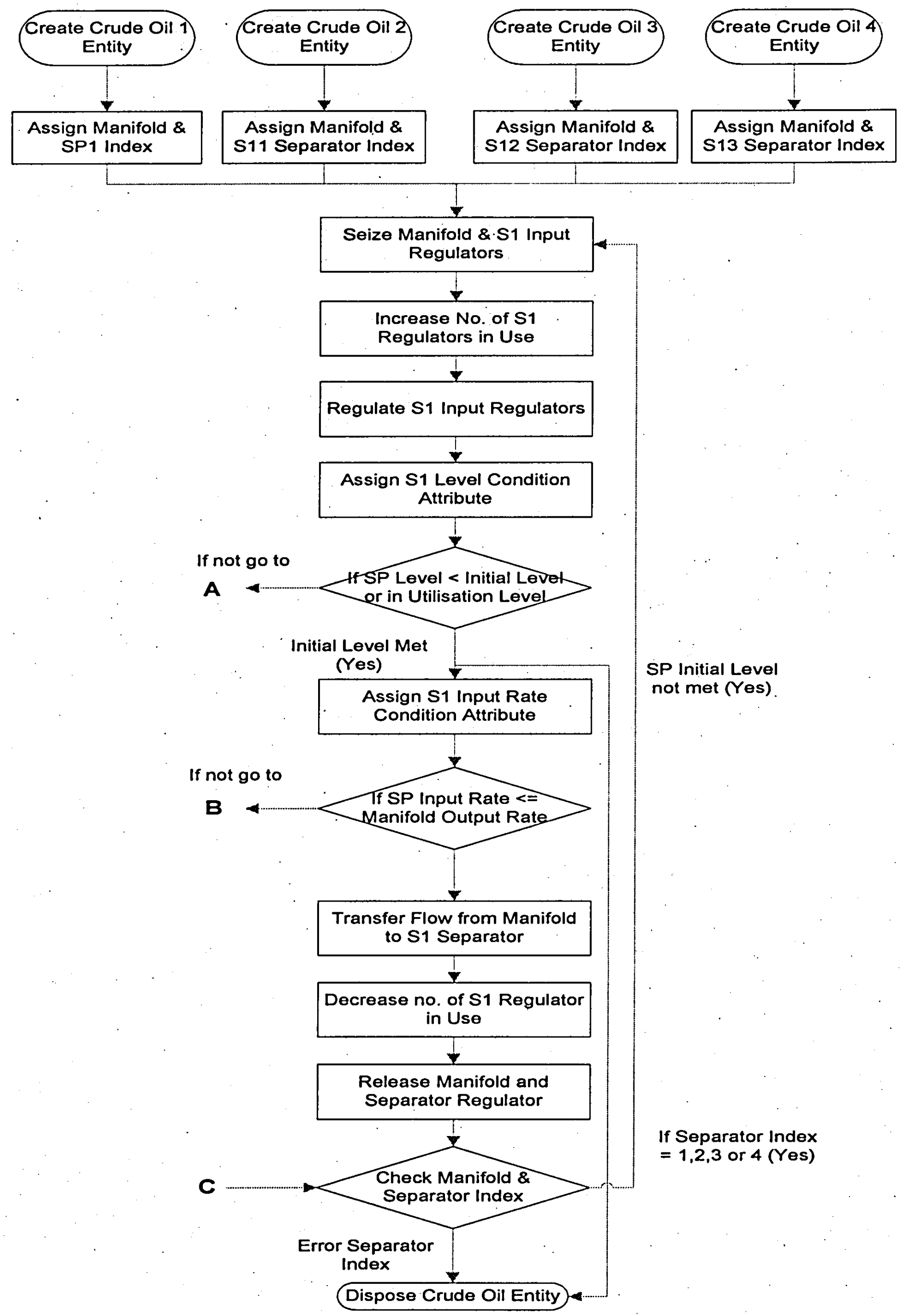
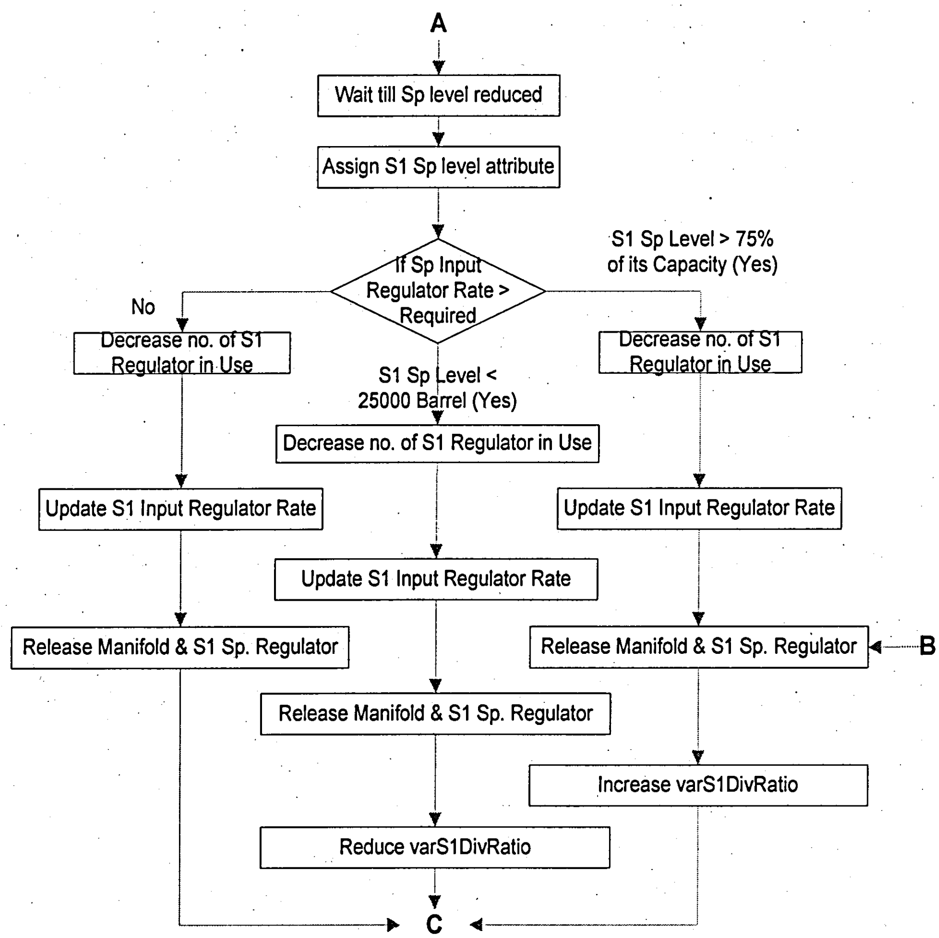
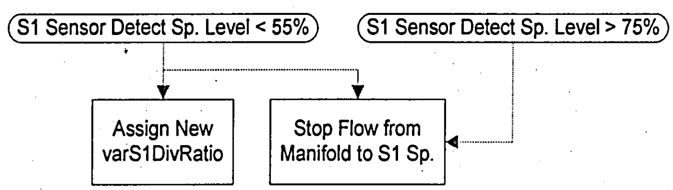


Figure 5.4 Flow-chart of Crude Oil Separation from Manifold to Stage 1 Separators

(count.)


A
Wait till Sp level reduced
Assign S1 Sp level attribute
If Sp Input Regulator Rate > Required
S1 Sp Level > 75% of its Capacity (Yes)
No
Decrease no. of S1 Regulator in Use
S1 Sp Level < 25000 Barrel (Yes)
Decrease no. of S1 Regulator in Use
Decrease no. of S1 Regulator in Use
Update S1 Input Regulator Rate
Update S1 Input Regulator Rate
Update S1 Input Regulator Rate
Release Manifold & S1 Sp. Regulator
Release Manifold & S1 Sp. Regulator
B
Release Manifold & S1 Sp. Regulator
Increase varS1DivRatio
Reduce varS1DivRatio
C


S1 Sensor Detect Sp. Level < 55%
S1 Sensor Detect Sp. Level > 75%
Assign New varS1DivRatio
Stop Flow from Manifold to S1 Sp.

5.4.3 The Separation-process from Stage 1 Separators to Stage 2 Separators

In the process-flow from S1 to S2 in figure 5.5, similar processes and modules were used but obviously the processes here were a lot simpler than in the previous stage. The entity type Oil 2 was created and waited until the level of S1-SP exceeded the initial level to allow the oil-flow over into the oil-weir to flow out. The attribute tank index name for each of the SP at their particular production-line was set according to the name of the SP such as SP1Index and SP2Index. These tank indexes were used to differentiate the entity by its attributes when choosing the regulator. The entity was then separated into two entities carrying the same data by using the Separate Module and entered the two separate lines for oil and gas flow.

The input regulator rate of S2-SP was set as equal to the output regulator rate of S1-SP and divided by 'varS2DivRatio = 1'. Oil and gas were the two outputs separated at this stage while the water was not yet separated. Oil Ratio 1 and Gas Ratio 1 were applied in the Regulate module to predefine the ratio of oil and gas from one barrel of crude oil.

*Oil 1 output-rate = S1 SP input-regulator rate * Oil Ratio 1*

*Gas 1 output-rate= S1 SP input-regulator rate * Gas Ratio 1*

The oil was then transferred from S1-SP to S2-SP and the gas was removed to the gas-plant which was not studied in this project. Two sensors were applied here for detecting the level changes and sending a signal to the flow module. The sensor, detecting a dropping level, would assign a new value to the 'varS2DivRatio' and raise it to a higher value to reduce the flow rate.

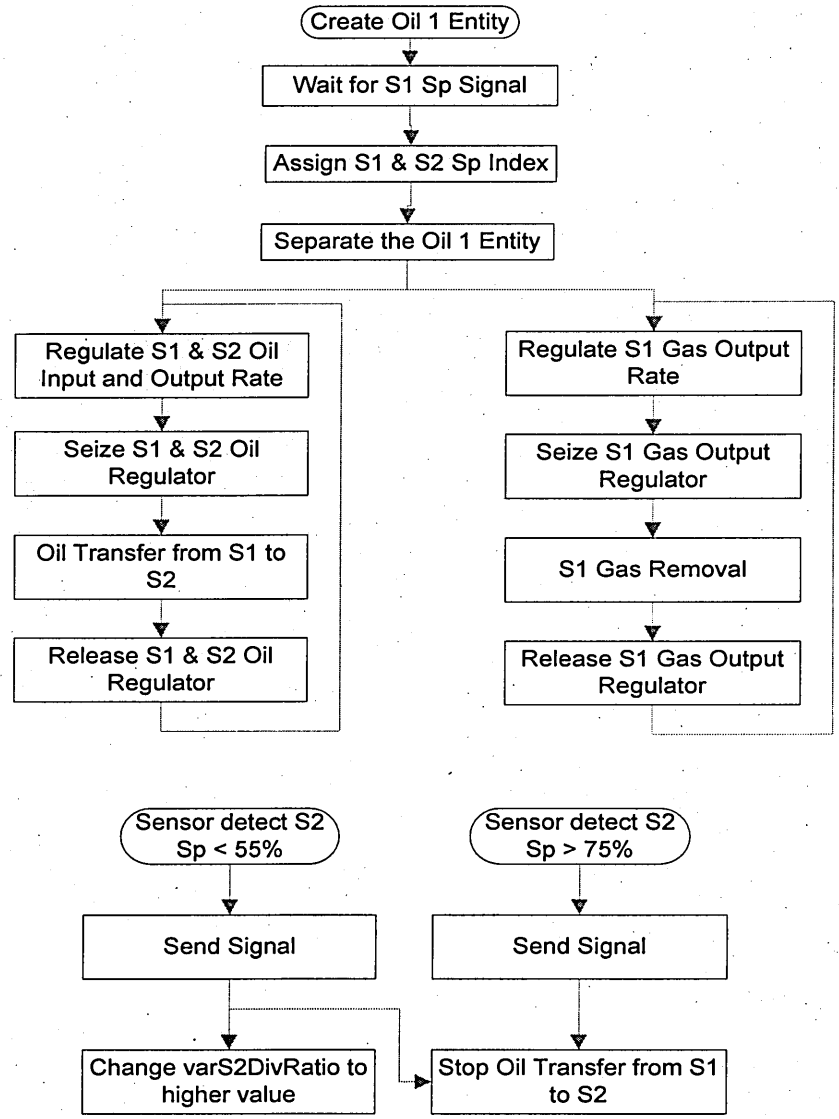


Figure 5.5 Flow-chart for Separation from Stage 1 to Stage 2

5.4.4 Separation Processes through Stage 2, 3 and 4

Due to the similarities with the processes from S2 to S3 and S3 to S4, the flowcharts in figure 5.6 and 5.7 were explained together. The SP used from S1 to S3 were in horizontal shape while the SP used in S4 were in vertical shape, called gas-boot, specially designed for separating redundant gas from oil. In figure 5.6, entity type Oil 2 was created and assigned with attribute SP2Index and SP3Index with value '1'. In figure 5.7, entity type Oil 3 was created and assigned with SP3Index and SP4Index at the same value. The water was separated at this stage and three entities were needed to activate the flow in three separate lines within the individual production-line. The Separate module was replaced by Duplicate block to create extra two copies of entity containing the same characteristics and data. Oil ratio 2, Gas Ratio 2 and Water Ratio 2 were inserted into the Regulate module as explained in the previous stage for figure 5.6. Oil ratio 3, Gas Ratio 3 and Water Ratio 3 were used in figure 5.7.

<u>S2 to S3 process:</u>

*Oil 2 output-rate = S2 SP input-regulator rate * Oil Ratio 2*

*Gas 2 output-rate = S2 SP input-regulator rate * Gas Ratio 2*

*Water 2 output-rate = S2 SP input-regulator rate *Water Ratio 2*

<u>S3 to S4 process:</u>

*Oil 3 output-rate = S3 SP input-regulator rate * Oil Ratio 3*

*Gas 3 output-rate = S3 SP input-regulator rate * Gas Ratio 3*

*Water 3 output-rate = S3 SP input-regulator rate * Water Ratio 3*

The water effluent from S2 and S3 SP flowed into the API oil-water separator to separate the excessive oil left in it. The oil was transferred from S2 to S3 SP in figure 5.6 and from S3 to S4 in figure 5.7 by the Flow module. Gas was removed and directed to the gas-plant. Two sensors for each of the S3 and S4 were included for detecting the errors caused by the level of SP.

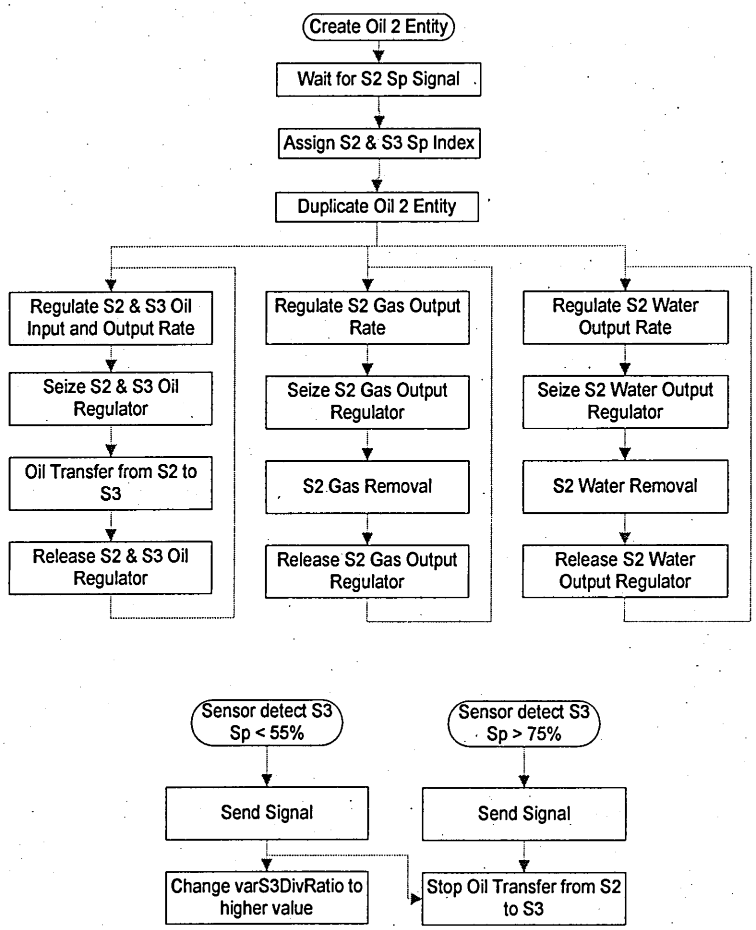


Figure 5.6 Flow-chart of Separation from Stage 2 to Stage 3

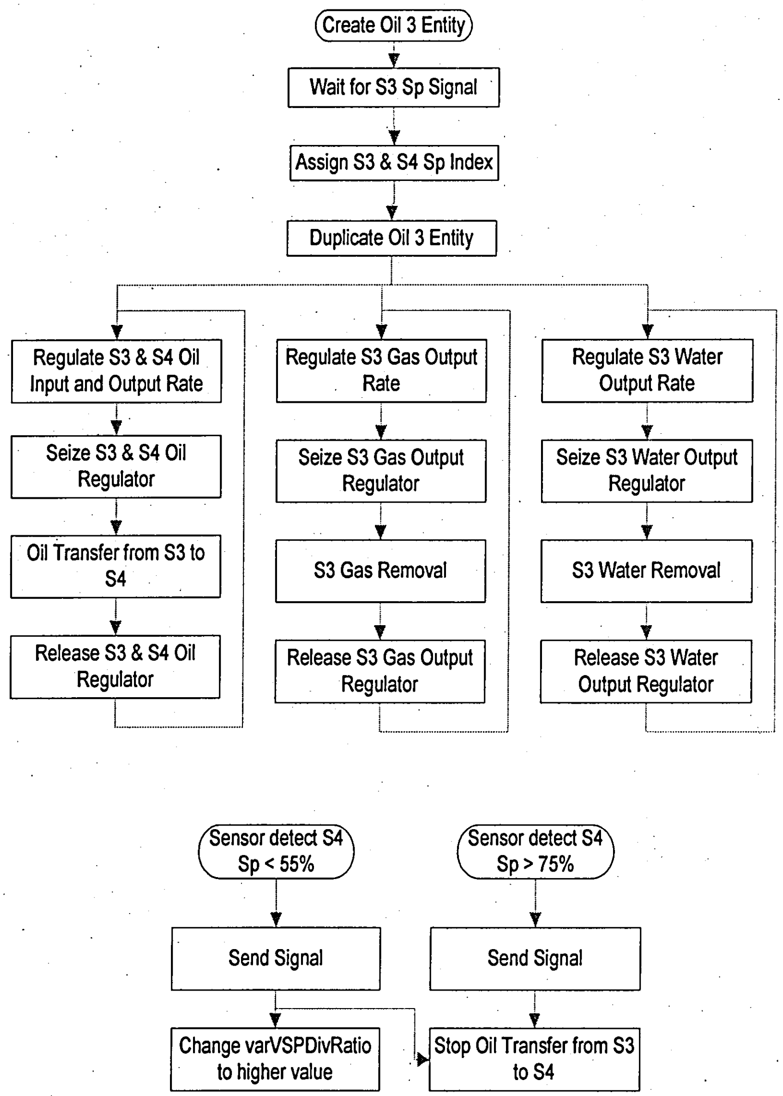


Figure 5.7 Flow-chart of Separation from Stage 3 to Stage 4

5.4.5 Separation Process from Stage 4 Separators to Stage 5 Storage-tanks

It was assumed that all the water had been separated in S3 and left over the little gas to be separated at S4 which was the final stage for the separation process. There were four operation-lines and four output-regulators on the lines. These output-regulators were connected to a large pipe, something similar to the manifold in the real system. The flow could be controlled by shutting down or opening the valve in order to allow the oil to flow to the designated tank. However, due to the complexity of modelling the piping in simulation, it was simplified by assuming the oil-output from line one and two flowed to storage-tank ST1 or ST3 when ST1 was full which normally happened only when there was an emergency for delivery. The output normally flowed straight out to the delivery-port or the Oil Centre at other plant. The same system assigned oil-output from line three and four to ST2 or ST4.

Oil 4 Entity was assigned with two attribute tank-indices as 'VSP1TankIndex' for VSP and 'ST_In1_Index' for ST. There were four sets of regulator specified in the Regulator Set Spreadsheet module. ST_In1_Regulator Set consisted of ST1_In1_Regulator, and ST3_In1_Regulator since the logic had been coded to flow into either ST1 or ST3. When the entity entered the oil-flow operation-line, it was important to pre-select which delivery-tank or storage-tank should be transferred to that to avoid any congestion or brimming incidents.

During the ST selection, the value of attribute 'ST_In1_Index' decided the ST to be used. Initially, the value of this attribute was assigned as '1'. When the entity entered this Assign module, the Boolean condition below took place, and if both the conditions *(((TankLevel(ST1) + 1E-8) > TankCapacity(ST1))* and *((TankLevel(ST3)*

+ 1E-8) < TankCapacity(ST3)))+(((TankLevel(ST1) + 1E-8) > TankCapacity(ST1)) && ((TankLevel(ST3) + 1E-8) < TankCapacity(ST3))) were correct, it would give a value '1', which meant if ST1 was full, the attribute-value was set to '2' after the summation. In here, it was automatically recognised that the value '2' was pointed to the second regulator set ST3_In1_Regulator. Therefore, when the 'ST_In1_Index' was equal to '1', it selected ST1. But when 'ST_In1_Index' was equal to '2', it selected ST3.

Equations:

1 + (((TankLevel(ST1) + 1E-8) > TankCapacity(ST1)) && ((TankLevel(ST3) + 1E-8) < TankCapacity(ST3)))+(((TankLevel(ST1) + 1E-8) > TankCapacity(ST1)) && ((TankLevel(ST3) + 1E-8) < TankCapacity(ST3)))

For the third and fourth production-line, the attribute 'ST_In3_Index' and 'ST_In4_Index' were initially set to '1', when ST3 was selected. When the conditions were both fulfilled, the attribute 'ST_In3_Index' and 'ST_In4_Index' would be changed to '2' and this selected ST4.

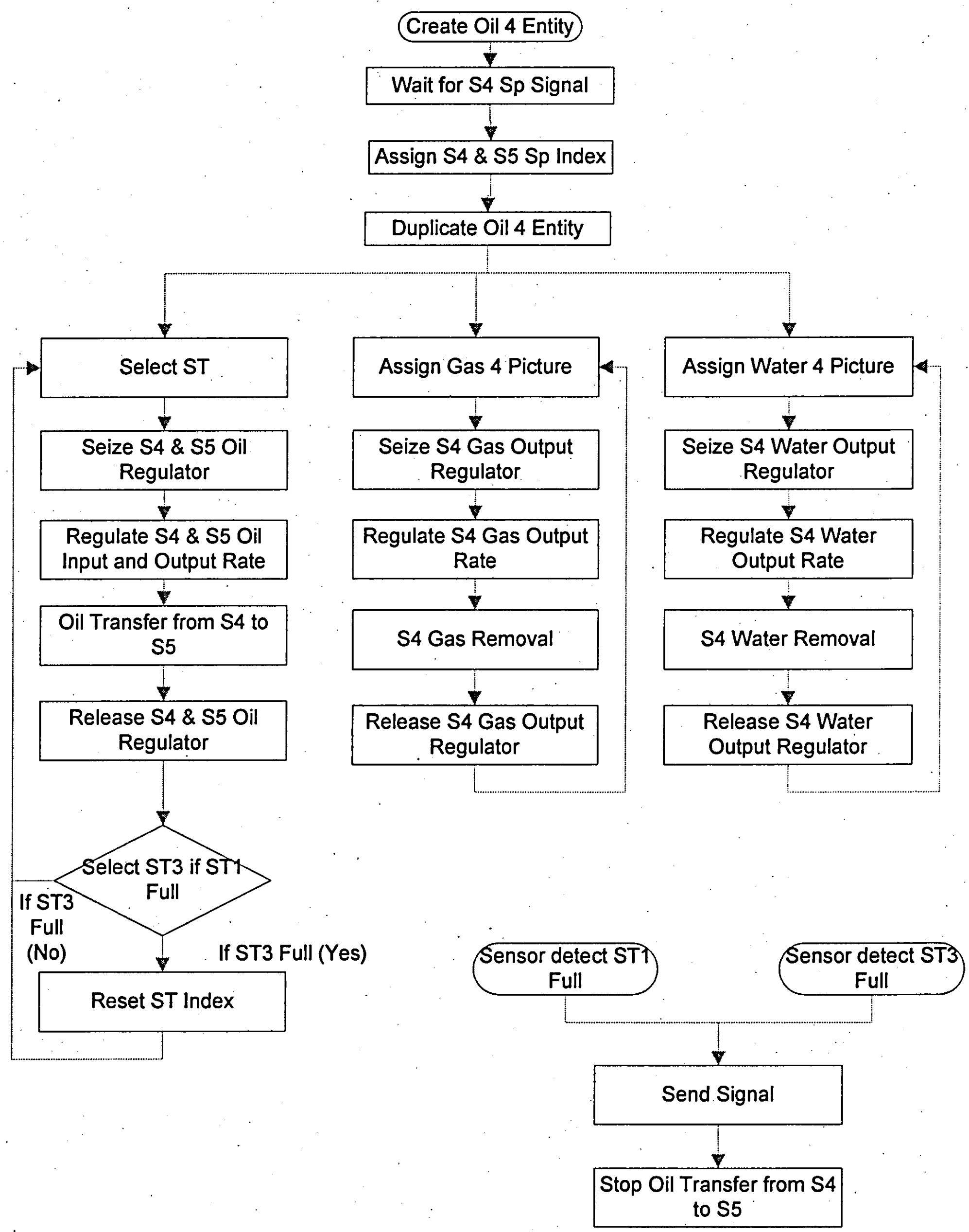


Figure 5.8 ARENA Flow-chart of Separation from Stage 4 to Stage 5

Equations:

1 + (((TankLevel(ST2) + 1E-8) > TankCapacity(ST2)) && ((TankLevel(ST4) + 1E-8) < TankCapacity(ST4)))+(((TankLevel(ST2) + 1E-8) > TankCapacity(ST2)) && ((TankLevel(ST4) + 1E-8) < TankCapacity(ST4)))

At the end of oil-transfer, the entity was released to a Decide module to check if the ST3 was full. If ST3 was full, the attribute 'ST_In1_Index' was assigned back to '1' for selection of ST1.

The process-flow for the gas and water-output was exactly the same as previous stages with a different name and amended ratio.

*Oil 4 output-rate = S4-SP input-regulator rate * Oil Ratio 4*

*Gas 4 output-rate = S4-SP input-regulator rate * Gas Ratio 4*

*Water 4 output-rate = S4-SP input-regulator rate * Water Ratio 4*

Since there was zero water-content at this stage, the ratio was equivalent to zero and gave zero output.

5.4.6 Separation Process from Stage 5 Separators to the setting up the Delivery

The last stage in this crude oil separation-process was the oil-transfer from the delivery-tank or storage-tanks to the Oil Centre Z.O.C 103A. The dynamic demand from the market could be simulated in this stage where an infinite number of entities could be created with distributed time between intervals. However, it was here set at constantly one minute with only one entity created. The entity created waited at the

Delay module until the level of the tank increased over 20 percent of its capacity to make sure there was oil to be transferred. Similar processes were carried out for assigning the attribute-index, regulating the flow-rate, setting up the seize-regulators, and removing gas and oil. At the end of the flow, if the current tank was empty, the entity moved into the ST3 and withdrew oil from there. The sensor sensed the empty tank and a stop signal would be sent out to stop the flow.

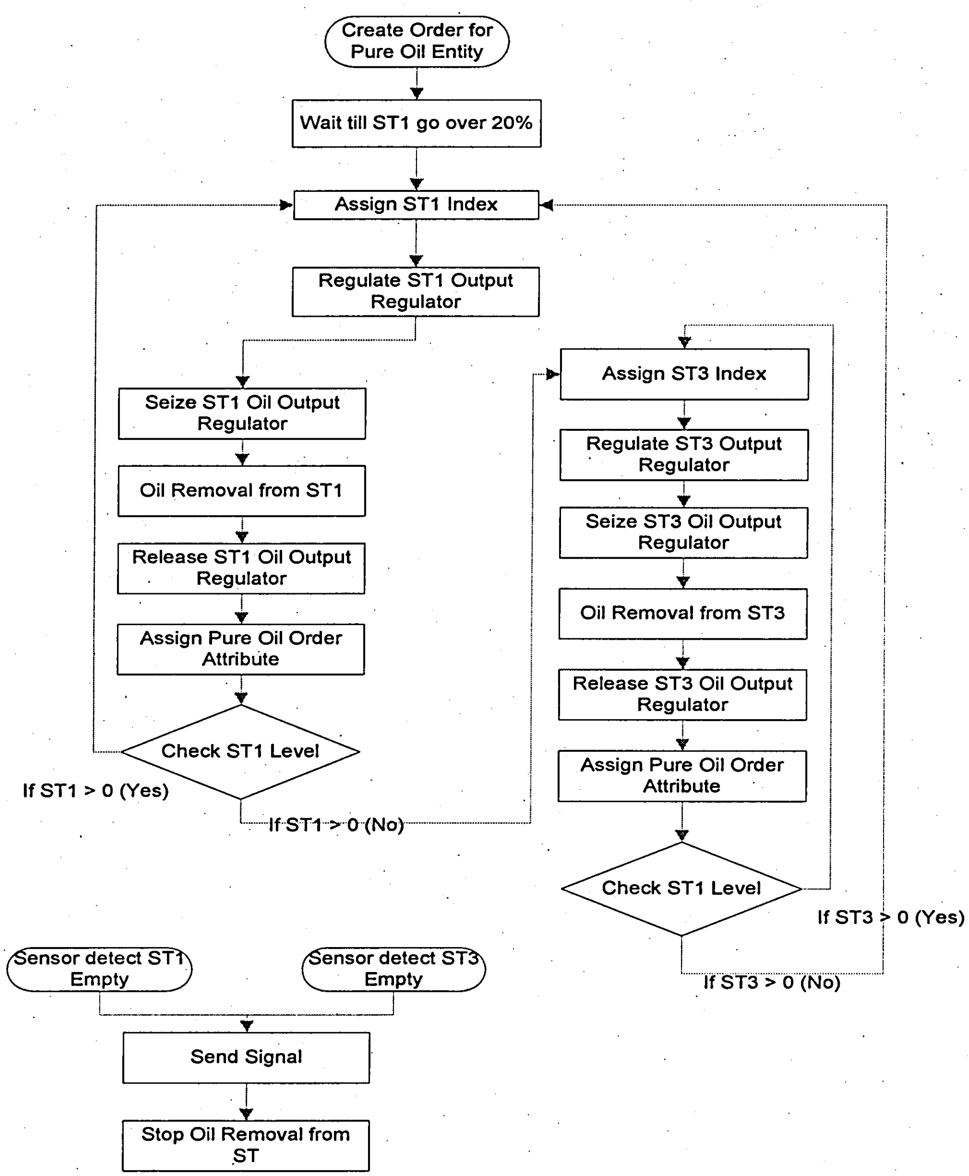


Figure 5.9 Flow-chart of Oil -transfer from Storage-tank (Lines 1&2)

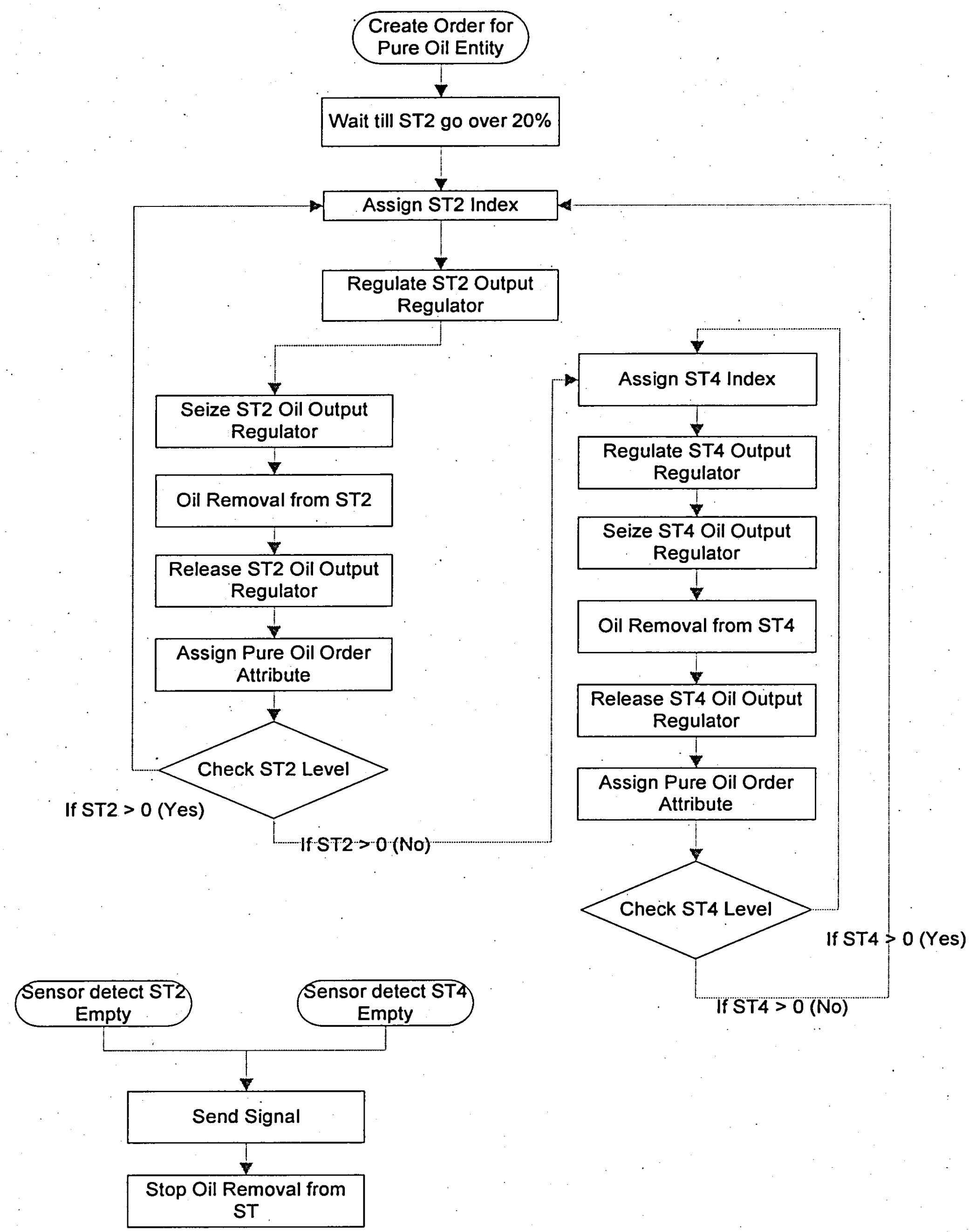


Figure 5.10 Flow-chart of Oil-transfer from Storage-tank (Lines 3&4)

5.5 Verification and Validation

Once the models had been constructed, they had to be tested, verified and validated. It was improper to assume that the models would behave as expected or imitate the real system without testing, verification and validation being carried out on them. What do verification and validation mean? "Verification is a process of ensuring that the model-design (conceptual model) has been transformed into a computer-model with sufficient accuracy" (Davis, 1992, cited by Robinson, 2004). Validation is, on the other hand, ensuring that the model is accurately representing the system in the real world with sufficient data. The verification could be carried out not only when the whole model was completed but, for best results, at every stage of the changes made.

5.5.1 Methods for Verification

There are various ways of verifying the models, however the methods used in this project were checking on the model-code, visual-checking and inspecting output-reports. The code or model-logics were documented in a log-book and meeting minutes for reference by the modeller. The discussions of any changes to be made were all recorded and referred back by the modeller. Besides, the logic-modules were given meaningful names so they were easily recognised and it was easily understood what process the modules were performing. The verification process is not restricted only to the modeller who has an idea how the model should perform, but is shared also by the person who is expert in this system on how the real system should behave. The two-way communications and discussions between the modeller and the person in charge of the real system are significant in coming to a satisfactory approach that both parties agreed. This documentation would also help to make it easier for the user and the person who has direct interaction with the system being modelled to understand the system at the time it was implemented. Therefore, the model-logics were properly checked to ensure that it was following the process flow-chart that had been agreed by both parties prior to the model-building.

A visual-checking method was carried out ever since the simple model was built. A few scenarios were set up with expected results and tested. At this stage the model had to be compared to the concept that was constructed, ensuring that events happened and the entity moved along the right path. The Step-button was used in checking the events which happened at every step. A slow speed was set for the entity movement to allow more time for checking where the entity moved.

Animation was useful in the visual-checks as well as stepping through the logic-modules. Both visual-checking by analysing the animation and tracing the entity or events taking place over time had to be applied together for the best model-verification results. Output-reports were inspected for verification-accuracy. If the output-results were not as expected, the modeller would have to go back to the beginning of the process where the entity was created and step through the model-logic again and again, and the variable or attribute-changes of the entity were inspected until the problem was found. This verification-process continued until a model that agreed as closely as possible with the real-world observations of the phenomena that had been set out had been obtained.

5.5.2 Verification and Validation Carried Out in the Model

How were the verification-processes carried out in this project? White-box validations were carried out in conjunction with the verification-processes. Robinson (2004) stated that the white-box validation is the process for "determining that the constituent parts of the simulation-model represent the real-world elements or parts with sufficient accuracy".

At the very beginning of the model-building, one production-line with two tanks was modelled with manifold and storage-tank (shown in figure 5.11) as a starting point. This model was built to understand how the continuous system worked and what the role was which the entity played in the continuous system. It facilitated an understanding of how the seize-regulator, flow- and release-regulator module worked with the entity and how the sensor representing the conceptual-model was used. By trial and error, different numbers of entities were created, results were checked and the run-time element bar and reports were inspected. Error-messages popped up before the simulation-run ended, mentioning that the entities created exceeded the limit set for the student-version. An investigation was carried out with the entity-queue and it was realised that the seize-regulator allowed only one entity to go through into the flow-module. If the activate-entity was not released, all the other entities created would queue up before the seize-regulator module. From here, it was understood that only one entity was needed and created to activate the flow-module without stopping. This verified that the flow was continuously activated as in the real separation-system, but of course this was based on the simulation run-length set in ARENA.

With only the model-logic at the left-hand side, the manifold became empty when the liquid was all transferred to the storage-tank. Therefore another logic called manifold logic was built to refill the manifold at all times. An entity was created by the sensor and triggered the flow-module. It only left the module when another sensor sensed maximum tank-level. This verified that the manifold was filled up with crude oil at all times as in the real system unless the wells were dried up. When the manifold was filled up as soon as the level dropped and crude oil flowed from the manifold to the storage-tank continuously, the storage-tank would brim over and caused leaking or malfunction in the system. This incident would never be allowed to happen in the real system. Storage-tank model-logic was added by using a sensor to sense the entity and this triggered the crude oil removal-process until the storage-tank was empty.

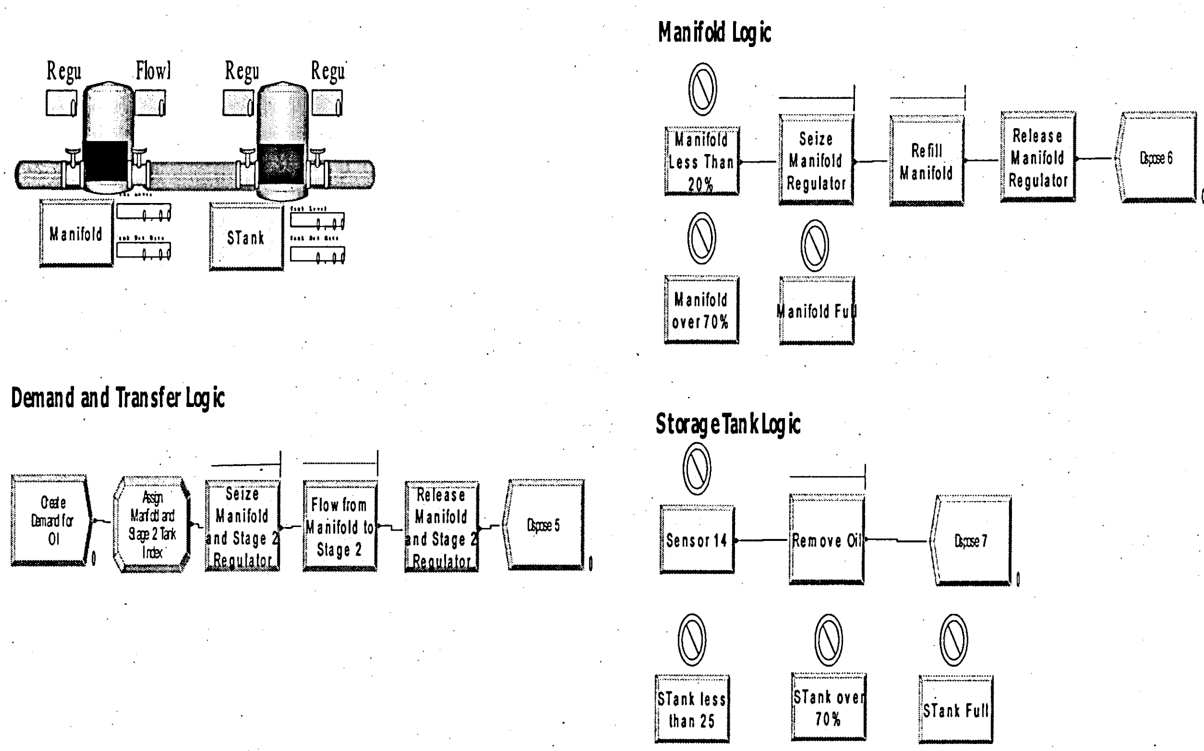


Figure 5.11 Basic Model-building and Testing

An extra tank-module was added later as S1 separator in between the manifold and storage-tank. The same testing and verification procedures were taken to ensure that the flow from the manifold to SP1 and from SP1 to the storage-tank gave the results expected. When the concept worked, the input-rates and capacity were changed, as has been discussed in section 5.3, to different figures for testing. If the model worked as expected, this model was verified. The procedures were repeated and checked back and forward until the whole production-line with four separators was added. When the first production-line was verified, the second, third and fourth could be added and modelled.

VBA codes were used for user-interface building to allow non-expert users to choose the different scenarios for experiments with the factors described. The codes were checked step by step ensuring the data or values stored as input were correct and the interface-form popped out at the right time before the run-replication was called in ARENA. The user did not need to understand the code written by VBA since the interface-form which popped up described how to choose input. Four different interface-forms were created, each of them tested and verified separately before they were all combined as one file. These verification-processes were carried out and agreed together by the author and the experts of this system through the verification-processes carried out above.

Through this example, it should be noted that the testing, verification and validation should be carried out as much as possible while building the model to avoid any confusion in searching for errors when the model grew more complex. That would cost more time and effort in error-identification or sometimes the modeller would give up and have to start the modelling again.

5.6 Conclusion

How to model the systems; what should be considered in the simulation-model as the input, experimental factors and outputs; how to gather and analyse the data; comments on the models built; and the verification and validation of models were all introduced in this chapter. The next chapter will describe experiments designed for this project which aimed to research how carefully-selected levels of the input-factors affected the output.

Chapter 6

Experiments and Results

6.1 Introduction

In the previous chapter the concept of the model was discussed which included the objectives of the simulation-model, flow-charts of the processes, data-collection, assumptions and experimental-factors. The model-building and description was explained and when the models had been constructed, they were tested, verified and validated too.

The experiments designed for this part of the thesis will be introduced in this chapter. They aimed to research how carefully-selected levels of the input-factors contributed to the output, so that the user will have just to key in the value for each of the factors to get the estimated output. Table 6.1 shows the factors to be investigated and their values. The first factor is the input-rate, which is the amount of oil input into the separators-area, and in these experiments four different input-rates will be used. The input-rate is indicated with a symbol (U1, U2, U3, and U4) and the amount of crude oil is measured by barrel-per-minute. The number of production-lines is four and they are indicated by A1, A2, A3 and A4. Also this table includes the quality of crude oil in terms of water-content and this is indicated with W1, W2, W3, W4, W5, W6 and W7 which give different values. The capacities of the crude oil separators are indicated with C1, C2 and C3 and they give three different values.

Table 6.1 Symbols and Values

Symbol	Description	Value
U1	Input-rate	5433.62 bbl/min
U2	Input-rate	7244.82 bbl/min
U3	Input-rate	10867.24 bbl/min
U4	Input-rate	21734.47 bbl/min
A1	No. of Production-line	1
A2	No. of Production-line	2
A3	No. of Production-line	3
A4	No. of Production-line	4
W1	Quality of Crude Oil	-75%
W2	Quality of Crude Oil	-50%
W3	Quality of Crude Oil	-25%
W4	Quality of Crude Oil	Original
W5	Quality of Crude Oil	+25%
W6	Quality of Crude Oil	+50%
W7	Quality of Crude Oil	+75%
C1	SP Capacity	32,500 (-35%)
C2	SP Capacity	50,000 (Original)
C3	SP Capacity	67,500 (+35%)

6.2 Experiments and Results

Factorial designs are the common experimental designs that most people would use such as 2^k or 3^k. However, the experiments to be carried out in this simulation-model contained more than three levels. Therefore, the mixed factorial designs were applied. When dealing with multiple-factors with a mixture more than four-level, it might not be possible to carry out all the experiments where sometimes the total number of experiments is 4^2 x 11^2, but this is very rare to come across. Giesbrecht and Gumpertz (2004) had suggested the pseudofactor methods for dealing with this type of experiment where the number of experiments could be reduced yet still offer a close estimation compared to values from all experiments.

As has been mentioned with the aims and objectives of this simulation-modelling, it was necessary to bring out the results for all interactions between factors. Two types of experiment were carried out. The first type of experiment was based on the interaction of crude oil arrival input-rates, the number of production-lines and water-content. Here, the capacity remained as the original value. The experiment design was based on 4 x 4 x 7 or 2^4 x 7 which was 112 runs for first type of experiment.

In the first set of type-one experiment, U1 was set unchanged but the number of lines and water-content changed gradually, as shown in table 6.2. The same experiments were carried out for table 6.3 to table 6.5, apart from the changes made from U1 to U4. The results were recorded in tables and will be discussed in Chapter 7.

Table 6.2 Set 1: Different Production-lines and Water-content with U1 Input-rate

Input Rate				No. of Lines				Quality of Crude Oil							Total Output (bbl/30 days)
U1	U2	U3	U4	A1	A2	A3	A4	W1	W2	W3	W4	W5	W6	W7	
1				1				1							912,520
1				1					1						858,340
1				1						1					804,150
1				1							1				749,970
1				1								1			695,780
1				1									1		641,600
1				1										1	587,410
1					1			1							1,825,000
1					1				1						1,716,700
1					1					1					1,608,300
1					1						1				1,499,900
1					1							1			1,391,600
1					1								1		1,283,200
1					1									1	1,174,800
1						1		1							2,737,520
1						1			1						2,575,040
1						1				1					2,412,450
1						1					1				2,249,870
1						1						1			2,087,380
1						1							1		1,924,800
1						1								1	1,762,210
1							1	1							3,650,000
1							1		1						3,433,400
1							1			1					3,216,600
1							1				1				2,999,800
1							1					1			2,783,200
1							1						1		2,566,400
1							1							1	2,349,600

Table 6.3 Set 2: Different Production-lines and Water-content with U2 Input-rate

Input Rate				No. of Lines				Quality of Crude Oil							Total Output (bbl/30 days)
U1	U2	U3	U4	A1	A2	A3	A4	W1	W2	W3	W4	W5	W6	W7	
	1			1				1							1,216,700
	1			1					1						1,144,400
	1			1						1					1,072,200
	1			1							1				999,960
	1			1								1			927,710
	1			1									1		855,460
	1			1										1	783,220
	1				1			1							2,433,400
	1				1				1						2,288,900
	1				1					1					2,144,400
	1				1						1				1,999,900
	1				1							1			1,855,400
	1				1								1		1,710,900
	1				1									1	1,566,400
	1					1		1							3,650,100
	1					1			1						3,433,300
	1					1				1					3,216,600
	1					1					1				2,999,860
	1					1						1			2,783,110
	1					1							1		2,566,360
	1					1								1	2,349,620
	1						1	1							4,866,800
	1						1		1						4,577,800
	1						1			1					4,288,800
	1						1				1				3,999,800
	1						1					1			3,710,800
	1						1						1		3,421,800
	1						1							1	3,132,800

Table 6.4 Set 3: Different Production-lines and Water-content with U3 Input-rate

Input Rate				No. Of Lines				Quality of Crude Oil							Total Output bbl/30 days)
U1	U2	U3	U4	A1	A2	A3	A4	W1	W2	W3	W4	W5	W6	W7	
		1		1				1							1,825,000
		1		1					1						1,716,700
		1		1						1					1,608,300
		1		1							1				1,499,900
		1		1								1			1,391,600
		1		1									1		1,283,200
		1		1										1	1,174,800
		1			1			1							3,650,100
		1			1				1						3,433,400
		1			1					1					3,216,600
		1			1						1				2,999,900
		1			1							1			2,783,100
		1			1								1		2,566,400
		1			1									1	2,349,700
		1				1		1							5,475,100
		1				1			1						5,150,100
		1				1				1					4,824,900
		1				1					1				4,499,800
		1				1						1			4,174,700
		1				1							1		3,849,600
		1				1								1	3,524,500
		1					1	1							7,300,200
		1					1		1						6,866,800
		1					1			1					6,433,200
		1					1				1				5,999,800
		1					1					1			5,566,200
		1					1						1		5,132,800
		1					1							1	4,699,400

Table 6.5 Set 4: Different Production-lines and Water-content with U4 Input-rate

Input Rate				No. of Lines				Quality of Crude Oil							Total Output (bbl/30 days)
U1	U2	U3	U4	A1	A2	A3	A4	W1	W2	W3	W4	W5	W6	W7	
			1	1				1							3,650,100
			1	1					1						3,433,400
			1	1						1					3,216,600
			1	1							1				2,999,900
			1	1								1			2,783,100
			1	1									1		2,566,400
			1	1										1	2,349,700
			1		1			1							7,300,200
			1		1				1						6,866,700
			1		1					1					6,433,200
			1		1						1				5,999,700
			1		1							1			5,566,300
			1		1								1		5,132,800
			1		1									1	4,699,300
			1			1		1							10,950,300
			1			1			1						10,300,100
			1			1				1					9,649,800
			1			1					1				8,999,600
			1			1						1			8,349,400
			1			1							1		7,699,200
			1			1								1	7,049,000
			1				1	1							14,600,400
			1				1		1						13,733,400
			1				1			1					12,866,400
			1				1				1				11,999,400
			1				1					1			11,132,600
			1				1						1		10,265,600
			1				1							1	9,398,600

Another extra experiment was carried out in more detail, to test only the crude oil input rate and SP capacity for one production-line. The SP capacity was fixed and the crude oil arrival-rate was altered by multiplying the percentage shown in the table 6.6 (a) and (b) by the original value.

Table 6.6 (a) Experiment for Changing Input-rate with Fixed Separator Capacity

Name of Separator	Amended Input Rate (Run for 30 Days or 43200 min)								
	-90%	-70%	-60%	-50%	-40%	-30%	-20%	-10%	Original
SP1 Capacity (bbl)	50000	50000	50000	50000	50000	50000	50000	50000	50000
SP1 Input (bbl/min)	2, 173	6, 520	8, 694	10, 867	13, 041	15, 214	17, 388	19, 561	21, 734
SP2 Input (bbl/min)	837	2, 513	3, 351	4, 188	5, 026	5, 863	6, 701	7, 539	8, 376
SP3 Input (bbl/min)	181	542	723	904	1, 084	1, 265	1, 446	1, 626	1, 807
VSP1 Input (bbl/min)	32	95	127	158	190	222	253	285	317
FINAL OUTPUT									
Total Output	299, 930	899, 910	1, 200, 000	1, 499, 900	1, 800, 000	2, 099, 900	2, 400, 000	2, 699, 900	2, 999, 800
SP1 Utilisation	52. 17%	56. 52%	58. 69%	60. 87%	63. 04%	65. 21%	67. 39%	69. 56%	71. 73%
SP2 Utilisation	50. 84%	52. 51%	53. 35%	54. 19%	55. 03%	55. 86%	56. 70%	57. 54%	58. 38%
SP3 Utilisation	50. 18%	50. 54%	50. 72%	50. 90%	51. 08%	51. 27%	51. 45%	51. 63%	51. 81%
VSP1 Utilisation	50. 03%	50. 10%	50. 13%	50. 16%	50. 19%	50. 22%	50. 25%	50. 29%	50. 32%

Table 6.6 (b) Experiment for Changing Input-rate with Fixed Separator Capacity

Name of separator	Amended Input (Run for 30 Days or 43200 min)							
	10%	20%	30%	50%	70%	90%	110%	125%
SP1 Capacity (bbl)	50000	50000	50000	50000	50000	50000	50000	50000
SP1 Input (bbl/min)	23, 908	26, 081	28, 255	32, 602	36, 949	41, 295	45, 642	48, 903
SP2 Input (bbl/min)	9, 214	10, 051	10, 889	12, 565	14, 240	15, 915	17, 590	18, 847
SP3 Input (bbl/min)	1, 988	2, 169	2, 349	2, 711	3, 072	3, 434	3, 795	4, 066
VSP1 Input (bbl/min)	348	380	412	475	539	602	665	713
FINAL OUTPUT								
Total Output	3, 299, 900	3, 599, 800	3, 899, 900	4, 499, 800	5, 099, 800	5, 699, 700	6, 299, 700	6, 749, 800
SP1 Utilisation	73. 91%	76. 08%	78. 25%	82. 60%	86. 95%	91. 30%	95. 64%	98. 90%
SP2 Utilisation	59. 21%	60. 05%	60. 89%	62. 56%	64. 24%	65. 91%	67. 59%	68. 85%
SP3 Utilisation	51. 99%	52. 17%	52. 35%	52. 71%	53. 07%	53. 43%	53. 80%	54. 07%
VSP1 Utilisation	50. 35%	50. 38%	50. 41%	50. 48%	50. 54%	50. 60%	50. 67%	50. 71%

In the second type of experiment, the same methods used in type-one experiments were applied, except that the water-content columns were replaced by columns for the capacities of separator as in table 6.7 to 6.10, and the utilisation of every separator was calculated by the developed equation below which was discussed before in Chapter 5.

*Utilisation = [(time*input rate) + initial level]/capacity*100%*

*Amount of crude oil flowing in = time*input rate*

Table 6.7 Set 5: Different Production-lines and SP capacity with U1 Input-rate

Input Rate				**No. of Lines**				**Capacity**			**Total Oil Output (Bbl/min)**	**Utilisation (%)**			
U1	**U2**	**U3**	**U4**	**A1**	**A2**	**A3**	**A4**	**C1**	**C2**	**C3**	**VSP1**	**SP1**	**SP2**	**SP3**	**VSP1**
				1				1			0	85.28%	76.92%	76.92%	76.92%
				1					1		749,970	55.43%	51.05%	50.23%	50.08%
				1						1	749,970	41.06%	37.81%	37.20%	37.10%
					1			1			0	85.28%	76.92%	76.92%	76.92%
					1				1		1,499,900	55.43%	51.05%	50.23%	50.08%
					1					1	1,499,900	41.06%	37.81%	37.20%	37.10%
						1		1			0	85.28%	76.92%	76.92%	76.92%
						1			1		2,249,870	55.43%	51.05%	50.23%	50.08%
						1				1	2,249,870	41.06%	37.81%	37.20%	37.10%
							1	1			0	85.28%	76.92%	76.92%	76.92%
							1		1		2,999,800	55.43%	51.05%	50.23%	50.08%
							1			1	2,999,800	41.06%	37.81%	37.20%	37.10%

Table 6.8 Set 6: Different Production-lines and SP capacity with U2 Input-rate

Input Rate				No. of Lines				Capacity			Total Oil Output (Bbl/min)	Utilisation (%)			
U1	U2	U3	U4	A1	A2	A3	A4	C1	C2	C3	VSP1	SP1	SP2	SP3	VSP1
	1			1				1			0	88.07%	76.92%	76.92%	76.92%
	1			1					1		999,960	57.24%	51.40%	50.30%	50.11%
	1			1						1	999,960	42.40%	38.07%	37.26%	37.12%
	1				1			1			0	88.07%	76.92%	76.92%	76.92%
	1				1				1		1,999,900	57.24%	51.40%	50.30%	50.11%
	1				1					1	1,999,900	42.40%	38.07%	37.26%	37.12%
	1					1		1			0	88.07%	76.92%	76.92%	76.92%
	1					1			1		2,999,860	57.24%	51.40%	50.30%	50.11%
	1					1				1	2,999,860	42.40%	38.07%	37.26%	37.12%
	1						1	1			0	88.07%	76.92%	76.92%	76.92%
	1						1		1		3,999,800	57.24%	51.40%	50.30%	50.11%
	1						1			1	3,999,800	42.40%	38.07%	37.26%	37.12%

Table 6.9 Set 7: Different Production-lines and SP capacity with U3 Input-rate

Input Rate				No. of Lines				Capacity			Total Oil Output (Bbl/min)	Utilisation (%)			
U1	U2	U3	U4	A1	A2	A3	A4	C1	C2	C3	VSP1	SP1	SP2	SP3	VSP1
		1		1				1			0	93.64%	76.92%	76.92%	76.92%
		1		1					1		1,499,900	60.87%	52.09%	50.45%	50.16%
		1		1						1	1,499,900	45.09%	38.59%	37.37%	37.15%
		1			1			1			0	93.64%	76.92%	76.92%	76.92%
		1			1				1		2,999,900	60.87%	52.09%	50.45%	50.16%
		1			1					1	2,999,900	45.09%	38.59%	37.37%	37.15%
		1				1		1			0	93.64%	76.92%	76.92%	76.92%
		1				1			1		4,499,800	60.87%	52.09%	50.45%	50.16%
		1				1				1	4,499,800	45.09%	38.59%	37.37%	37.15%
		1					1	1			0	93.64%	78.53%	76.92%	76.92%
		1					1		1		5,999,800	60.87%	51.05%	50.45%	50.16%
		1					1			1	5,999,800	45.09%	37.04%	37.37%	37.15%

Table 6.10 Set 8: Different Production-lines and SP capacity with U4 Input-rate

Input Rate				No. of Lines				Capacity			Total Oil Output (Bbl/min)	Utilisation (%)			
U1	U2	U3	U4	A1	A2	A3	A4	C1	C2	C3	VSP1	SP1	SP2	SP3	VSP1
			1	1				1			0	110.36%	76.92%	76.92%	76.92%
			1	1					1		2,999,900	71.73%	54.19%	50.90%	50.32%
			1	1						1	2,999,900	53.14%	40.14%	37.71%	37.27%
			1		1			1			0	110.36%	76.92%	76.92%	76.92%
			1		1				1		5,999,700	71.73%	54.19%	50.90%	50.32%
			1		1					1	5,999,700	53.14%	40.14%	37.71%	37.27%
			1			1		1			0	110.36%	76.92%	76.92%	76.92%
			1			1			1		8,999,600	71.73%	54.19%	50.90%	50.32%
			1			1				1	8,999,600	53.14%	40.14%	37.71%	37.27%
			1				1	1			0	110.36%	76.92%	76.92%	76.92%
			1				1		1		11,999,400	71.73%	54.19%	50.90%	50.32%
			1				1				11,999,400	53.14%	40.14%	37.71%	37.27%

6.3 Conclusion

In this chapter, the experimental designs for this part of the thesis were discussed, which aimed to investigate the effect of selected levels of the input-factors on the output. In the first type of experiment, the interaction of the input-rate, number of lines and water content with crude oil output were examined. Another extra experiment was run to test the crude oil input-rate and SP capacity for one production-line where the SP capacity was fixed.

In the second type of experiment, separators of selected capacities were studied and also the utilisation of every separator was calculated. The results of the experiments were recorded and will be discussed and analysed using SPSS software in the next chapter.

Chapter 7

Results Analysis and Discussions

7.1 Introduction

In the preceding chapter, experimental designs for the simulation-model were discussed, and different experiments were run to study the effect of many factors on oil-output.

This chapter discusses and analyses the simulation-results obtained from a total of 177 runs through which different variables at different levels were examined. Of the 177 runs, 112 runs focussed on the effect of the crude oil input-rate, number of production-lines and the quality of crude oil. The other 48 runs focussed on the crude oil input-rate, number of production-lines and the capacity of the separators. The extra 17 runs focussed only on the crude oil input-rate and the capacity of the separators. The results were automatically reported in a Notepad file by ARENA software and the output-results for the oil produced were transferred to an Excel file for graphical representation. SPSS was used to analyse the obtained results.

7.2 Input-rate and Number of Production-lines Versus the Quality of Crude Oil

It was obvious that all the figures 7.1 to 7.5 were linearly-reduced. Starting from figure 7.1, only one input-rate was assigned to four different production-lines A1, A2, A3, and A4. By focussing on the W4, the original amount of water-content in the crude oil, the number of production-lines remained the same in this set of experiments, but the crude oil input-rates increased outputs from 749,970 bbl/30days to 2,999,800 bbl/30days. The data for producing 100,000 bbl/day of oil was calculated to be 21,734.47 bbl/min or 31,297,636 bbl/day which assumed that the pipe was able to handle such amount of input. Although there were 200 barrels of difference between the actual data and the results collected, this was considered very close to actual data with 0.007 percent of difference for 30 days. From here, it could be said that the major driver to this phenomenon was the crude oil arrival-rate to the separators. The difference in the output for an ideal system versus the model showed the system was affected by the time. The queuing-time waiting for the signal or waiting for the level to rise over the initial level or drop to an allowable level was the reason for the time spent on nothing. The less time the entity had for the flow-transfer, the less output it would provide. Besides, the calculation and the difference with the decimal places in the calculation by the ARENA software might be another reason which caused the difference.

Taking the quality of crude oil into the experiment, the linear-lines were gradually reduced. The experiment was started with W1, 75 % less than the original water-content in the crude oil, rising to W7, with a 75 % increase on the original water-content value. For example, if the water-content was 8,000 barrels, W1 would be 2,000 barrels. On the other hand it was 14,000 barrel for W7. At line U1A4, the maximum output shown was 3,650,000 barrels of oil per 30 days, nearly 22 % greater than the original oil-output whilst it was reduced at the same percentage for output at W7. Why was the oil-output not reduced or increased by 75%? This was because the gas was also increased and reduced while the percentage of the water-content in the crude oil changed, as mentioned in the assumptions in Chapter 5. The results and graphs showed the existence of water played a role in the quality of the crude oil. The more water in the crude oil, the less oil could be extracted.

Figures 7.2 to 7.4 show the same phenomenon despite the changes made to the crude oil arrival-rates which increased the oil-output. This can be better observed in figure 7.5 where all the results for four sets of experiments were plotted together in one graph.

There were two sets with two lines lapped over each-other and another set with four lines. Line U1&A2 was overlapped with line U3&A1. Lines U1&A4, U2&A3, U3&A2 and U4&A1 overlapped each-other, whilst line U4&A2 overlapped line U3&A4. The overlapping phenomenon showed that these lines were having the same output-results. The decision-maker would be able to adjust and decide how many production-lines were needed if 10,000 bbl/day of oil were to be produced depending on the crude oil input-rate. If the number of production-lines was set to one, the input-rate should be A4, the maximum assumed in this project. If all the production-lines were activated, lower input-rates were needed unless more output was needed or the higher utilisation was required. However, the utilisation would change depending on the input-rate and capacity (which will be discussed later).

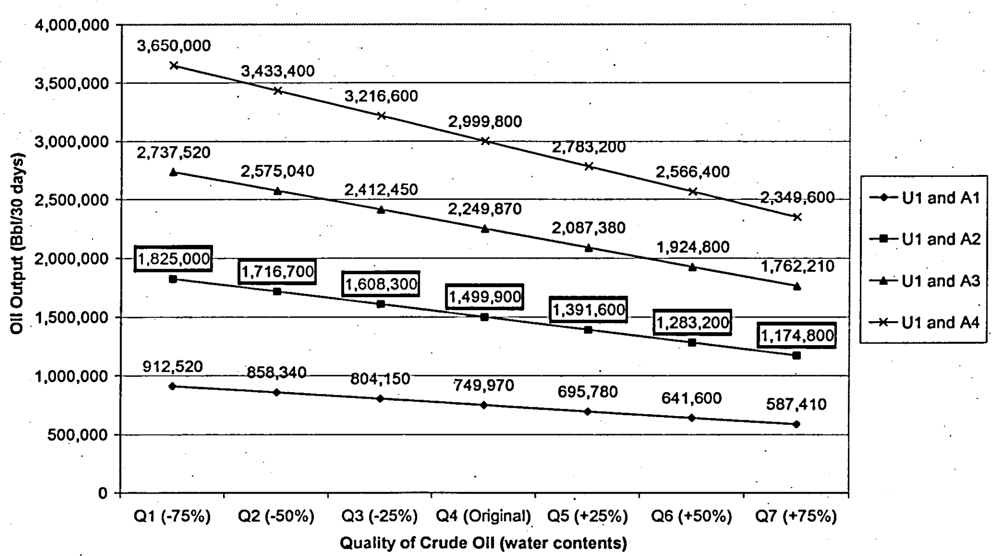


Figure 7.1 Oil Output against Water-content with Four Production-lines with Input-rate U1

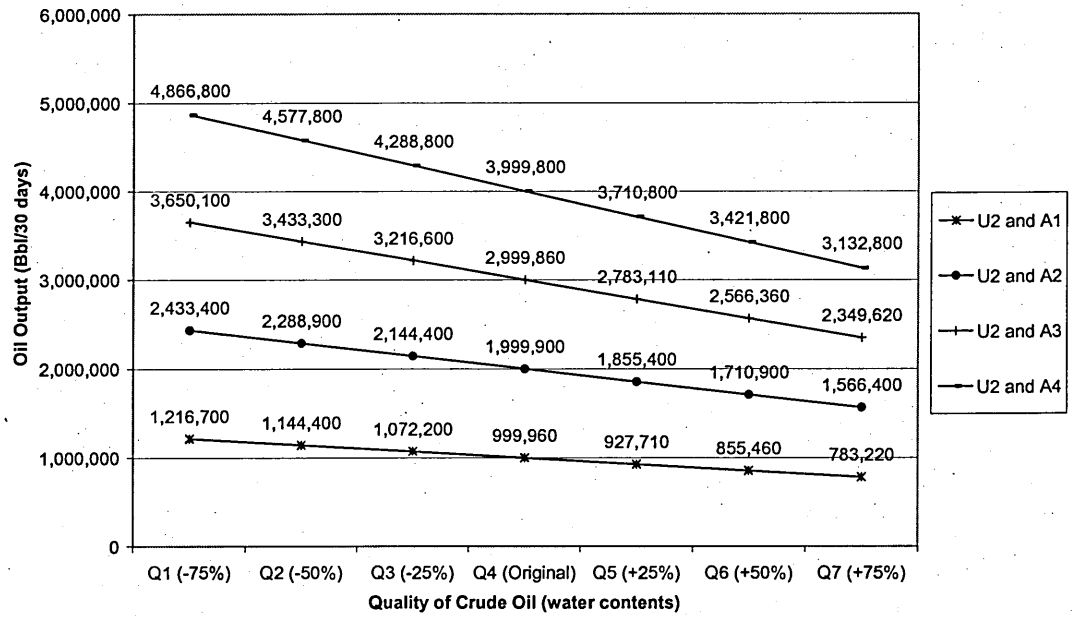


Figure 7.2 Output against Water-content with Four Production-Lines with Input-rate U2

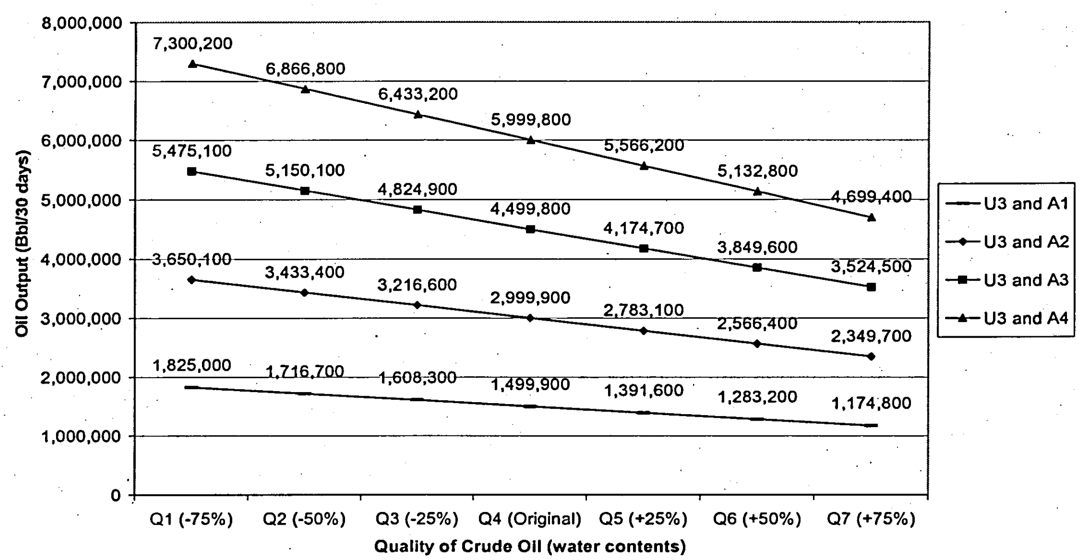


Figure 7.3 Output against Water-content with Four Production-lines with Input-rate U3

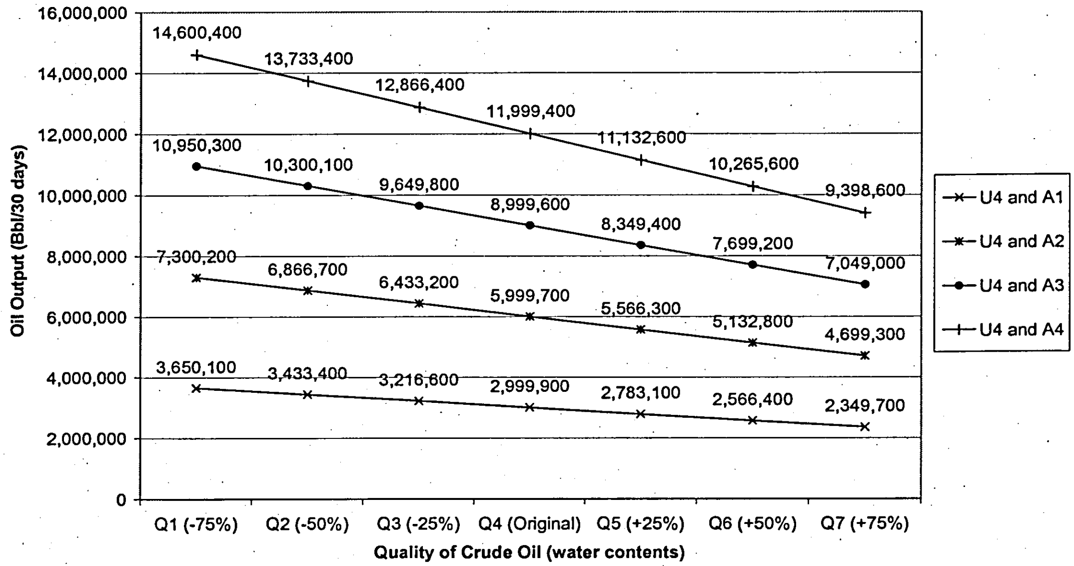


Figure 7.4 Output against Water-content with Four Production-lines with Input-rate U4

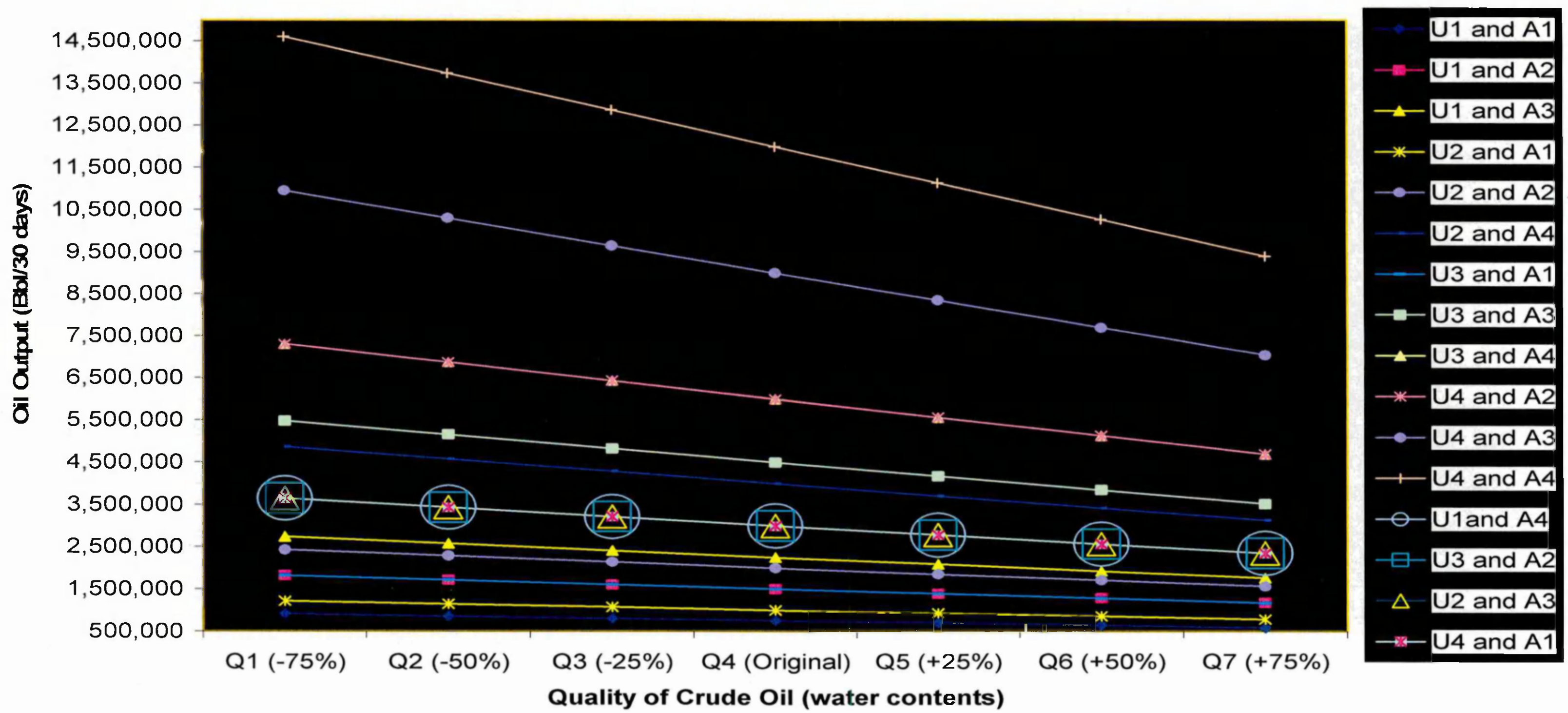


Figure 7.5 Output against Water-content by combining Figure 7.1 to Figure 7.4

7.3 Input-rate and Number of Production-lines Versus SP Capacity

A selected range of experiments were carried out for testing the effects of the input-rates on the capacity of the separator and the number of production-lines. The oil input-rate and the capacity of separator play an important role in the separator utilisation.

The input-rates were altered from its original value as mentioned in Chapter 6. It is obvious from figure 7.6 that the less the crude oil which entered the SP, the less output was produced. In this experiment, the initial level of all the separators was pre-filled to half of their original capacity, which results in a minimum of 50 percent utilisation. A smaller separator is unable to handle the amount of crude oil that flowed in at a higher rate than allowed, which will be discussed in later figures. The SP utilisations for the experiments can also be found in figure 7.7. In order to achieve the maximum utilisation, the oil input-rate has to be increased to 48,903 barrel / minute with 50,000 barrel of capacity.

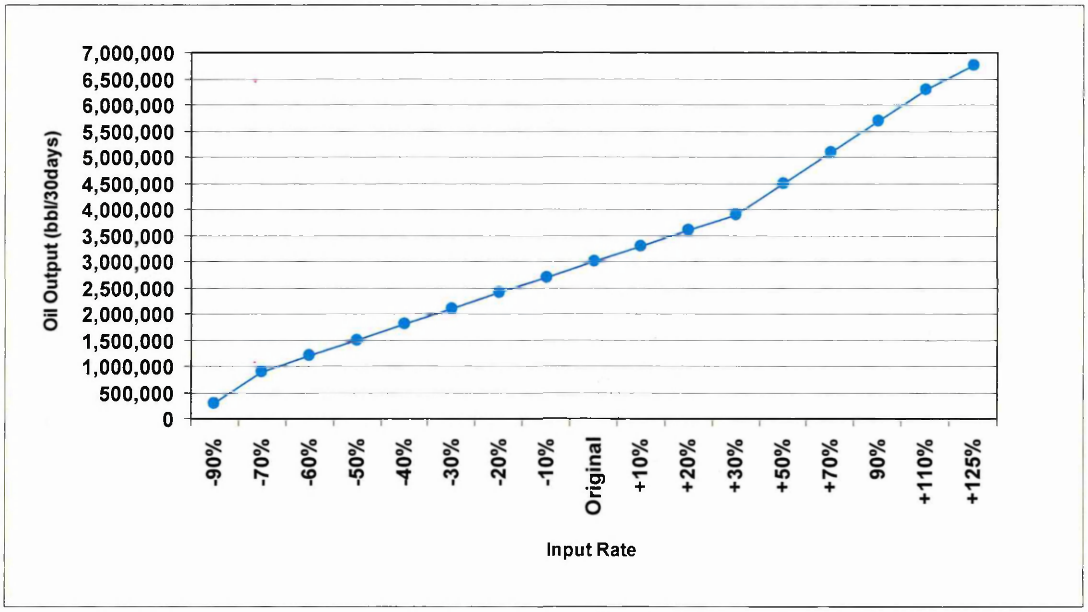


Figure 7.6 Oil-output with different Input-rate

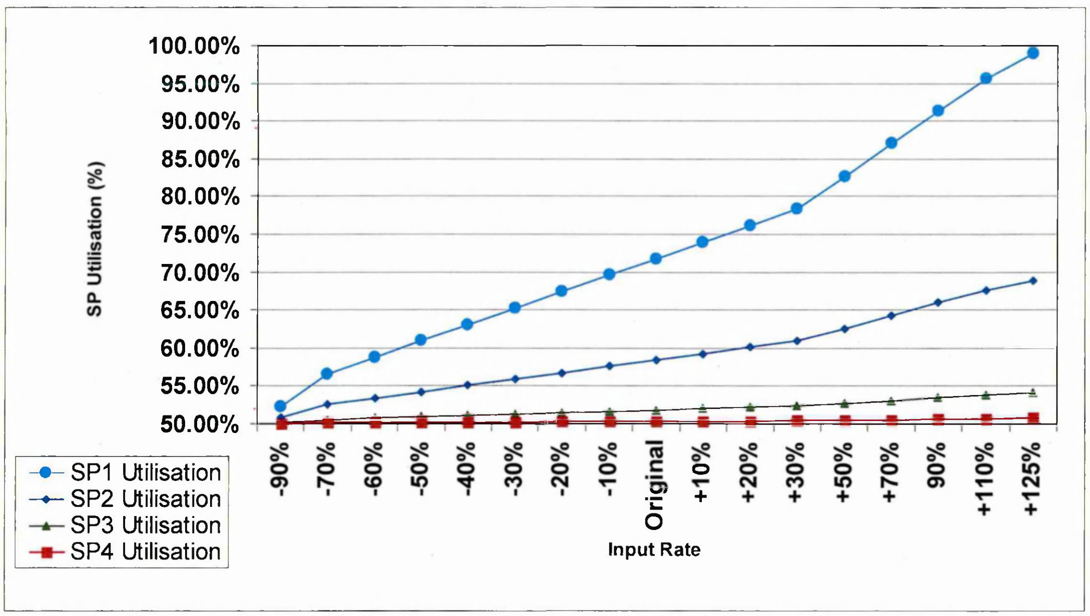


Figure 7.7 SP Utilisation

Another scenario used only three different capacity-levels, reduced by 35% from the original capacity, original capacity and increased by 35% from the original capacity. In this experiment, the output at point -35% was zero, and both the outputs at the original capacity and at +35% had the same value as shown in figure 7.8 to 7.12. The values of utilisation were calculated based on the input-rate for each of the different separators. Every separator had a different utilisation-value. The simulation- model was designed to dispose of the entity which was used to trigger the separation-process when the oil input-rate exceeded the maximum level that the separator could handle. At point -35%, the inserted oil amount exceeded the separator-capacity. Therefore, the created entity was disposed of and no process was activated. If the SP capacity was enlarged while the oil input-rate remained the same, output would not be increased. In fact the utilisation of the separator would be reduced. The utilisation below 50 percent is considered as underutilised, which means more resources would be invested for nothing, while the utilisation over 80 percent is considered high.

From the analysis above, the crude oil input-rate is acting as the main factor in altering the oil-outputs. Besides, the number of production-lines also contributes to the increment and decrement of the oil-output but not the separator utilisation. More production-lines activated at a higher input rate tend to give more output. The quality of crude oil is important to determine if more oil or water will be produced at the end. The capacity of the SP has to be at balance-point in order to achieve the required amount of oil at reasonable utilisation without wasting resources. The common utilisation in the oil-production industry is averagely around 60 percent in order to allow more oil to be produced when necessary.

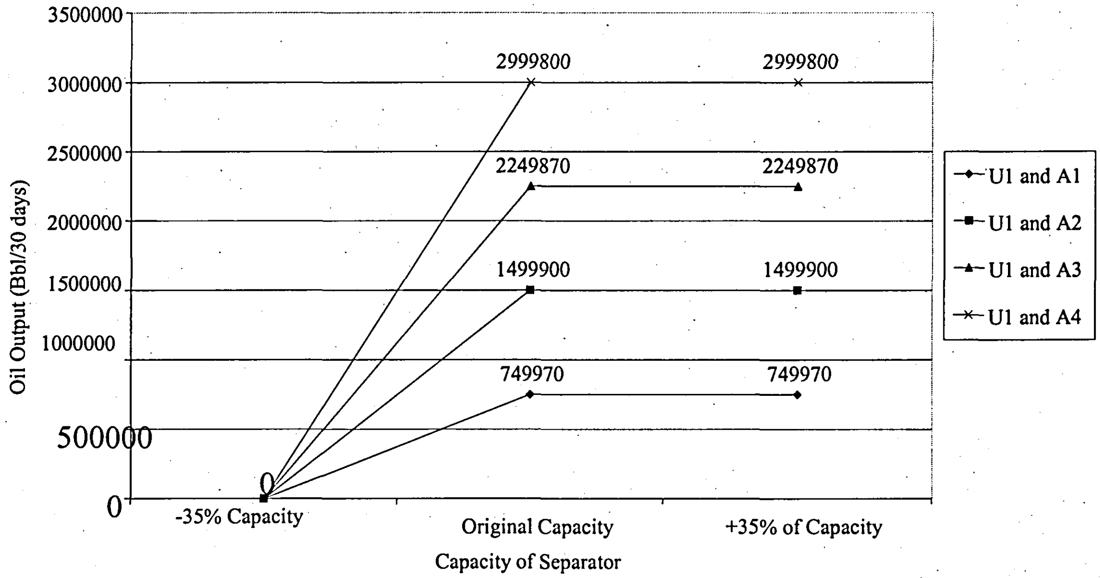


Figure 7.8 Output against SP Capacity with Four Production-lines with Input-rate U1

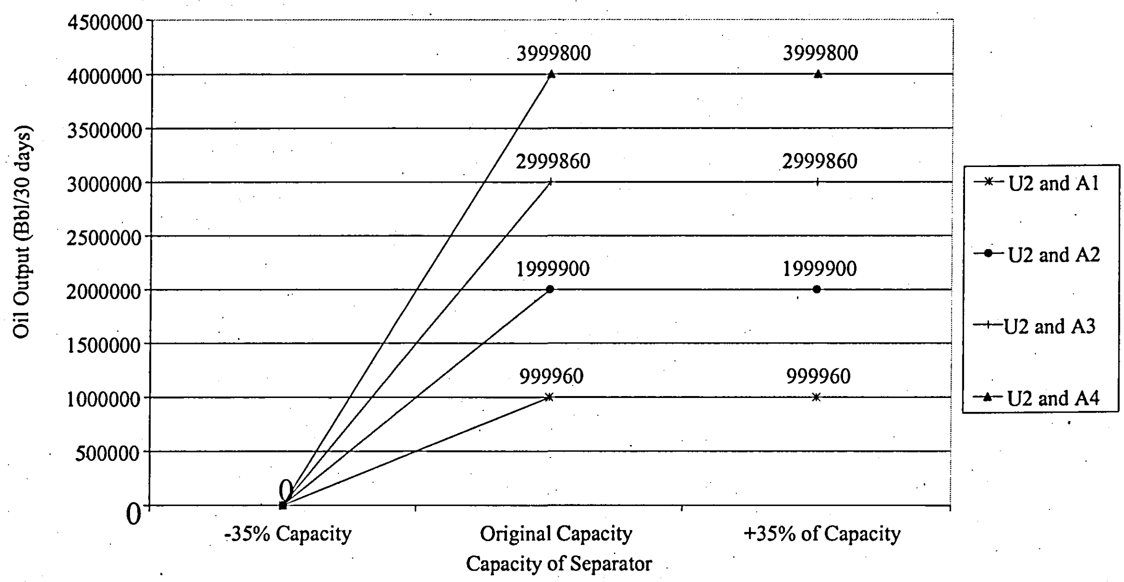


Figure 7.9 Output against SP Capacity with Four Production-lines with Input-rate U2

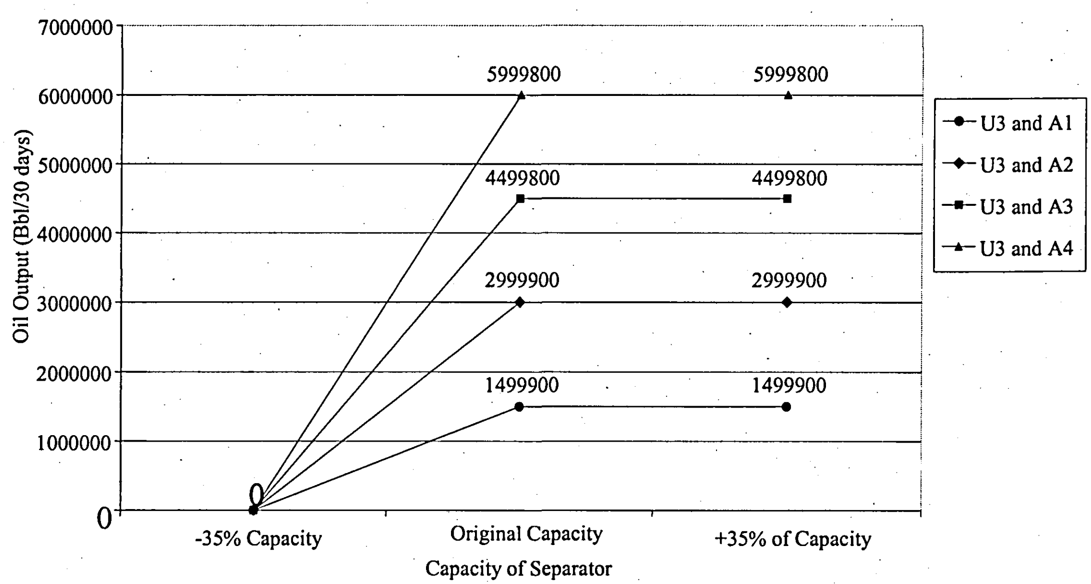


Figure 7.10 Output against SP Capacity with Four production-lines with Input-rate U3

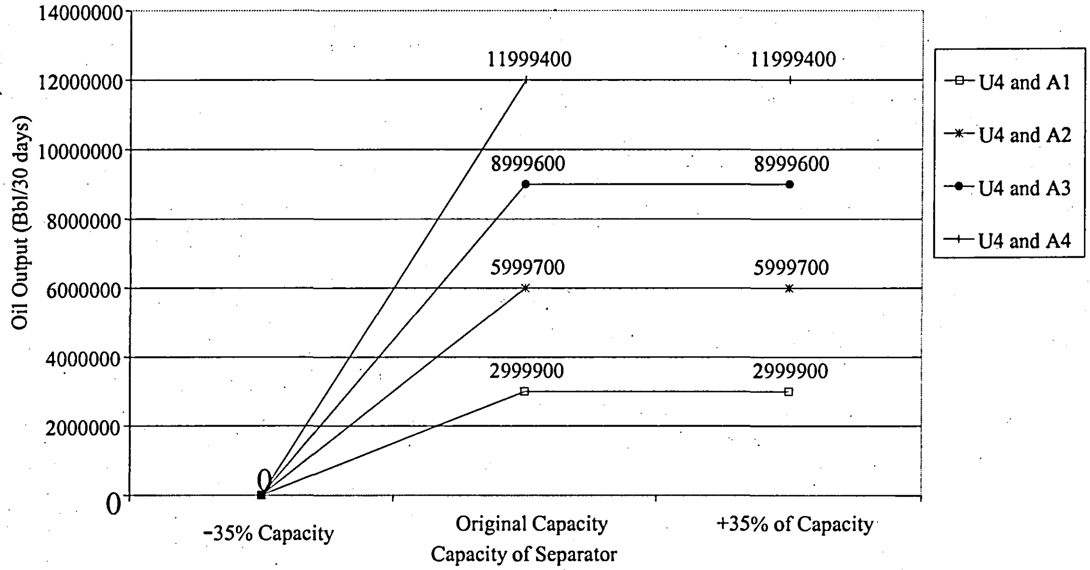


Figure 7.11 Output against SP Capacity with Four Production-lines with Input-rate U4

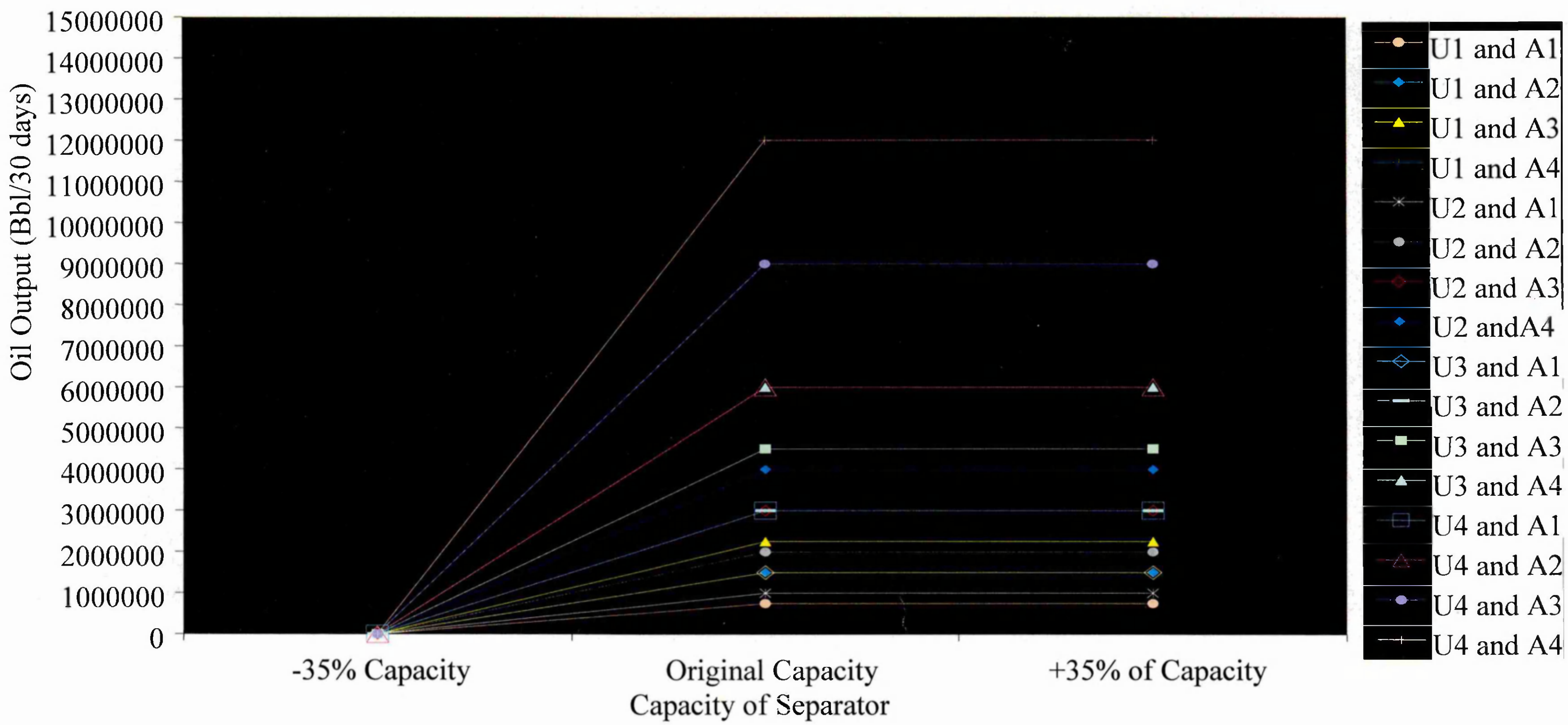


Figure 7.12 Output against SP Capacity by combining Figure 7.8 to Figure 7.11

7.4 Results Analysis

7.4.1 Choosing a Statistical Test

The selection of statistical test depends on several considerations, including:

1. Your research question.

2. The plan, or design, of your research.

3. The nature of the data that you wish to analyse.

In general, a significant factor in deciding upon a statistical analysis is whether the research is experimental or a consideration of existing data. The experimenter is usually interested in making comparisons between the average performance-levels of participants tested under different conditions. Analysis of variance (ANOVA) and t-test are statistical methods which were designed for the purpose of making comparisons (Kinnear and Gray 2008).

7.4.2 ANOVA (analysis of variance)

This method was developed by Sir Ronald Fisher in the 1930s as a way to interpret the results from agricultural experiments.

ANOVA is a statistically-based, objective decision-making tool for detecting any difference in average performance of groups of items tested (Bagci 2006).

The purpose of the experiments was to determine the relationships between different factors and the performance-measure and to analyse how these factors affect the performance.

The experiments were analysed by using SPSS software (multi-way ANOVA).

The purpose of using ANOVA is to study which factors are important and how much these factors affect the performance-measure (oil-output), because some factors can have a large effect on production and this affects the performance-measure of the production; and other factors have a medium or small effect.

Therefore ANOVA was used to study the effect of the four factors under investigation on the oil-output. The factors are the input-rate, the number of lines, the oil-quality and the capacity of the separators.

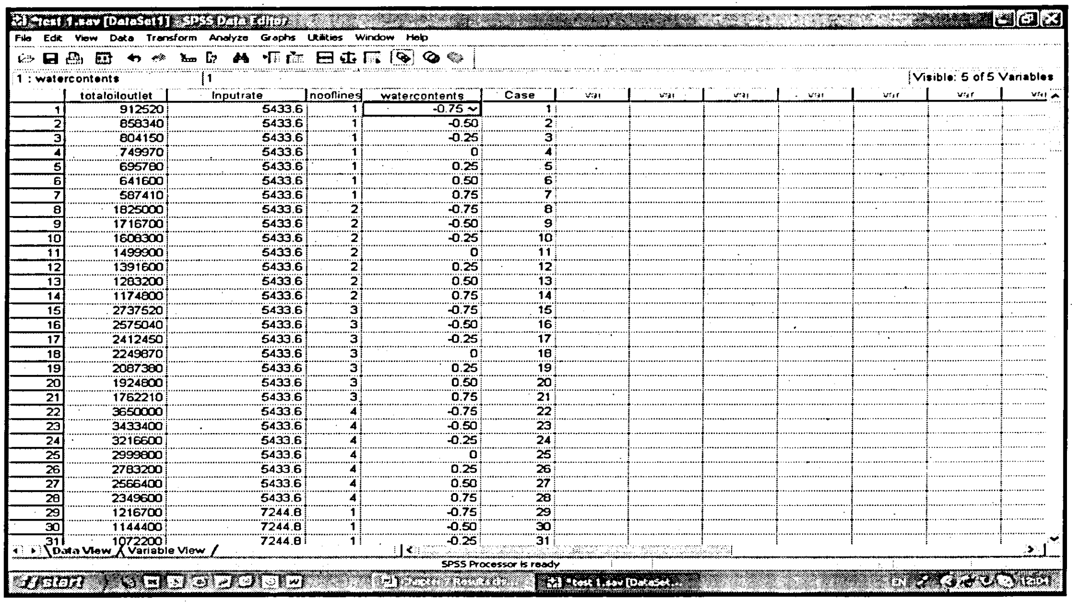
The input-rate: the rate at which the crude oil enters the separators area.

The number of lines: the production area contains four separator-trains (lines), which start from the first stage to the end, which is the fifth stage.

The oil-quality: the quality of crude oil is determined by many factors, but in this study we consider the percentage of water in the oil.

The capacity: the available capacity of the crude oil separators.

The first experiment was studying the effect of three factors, which are the input-rate, the number of lines and the oil-quality, on the performance-measure, which is oil-output. The data were transferred into the SPSS as shown in figure 7.13 and 7.14 and analysed by using Univariate Analysis of Variance. The results are shown in table 7.1 and plots of the statistical results are shown in figures 7.15-7.21.


*test 1.sav [DataSet1] - SPSS Data Editor

File Edit View Data Transform Analyze Graphs Utilities Window Help

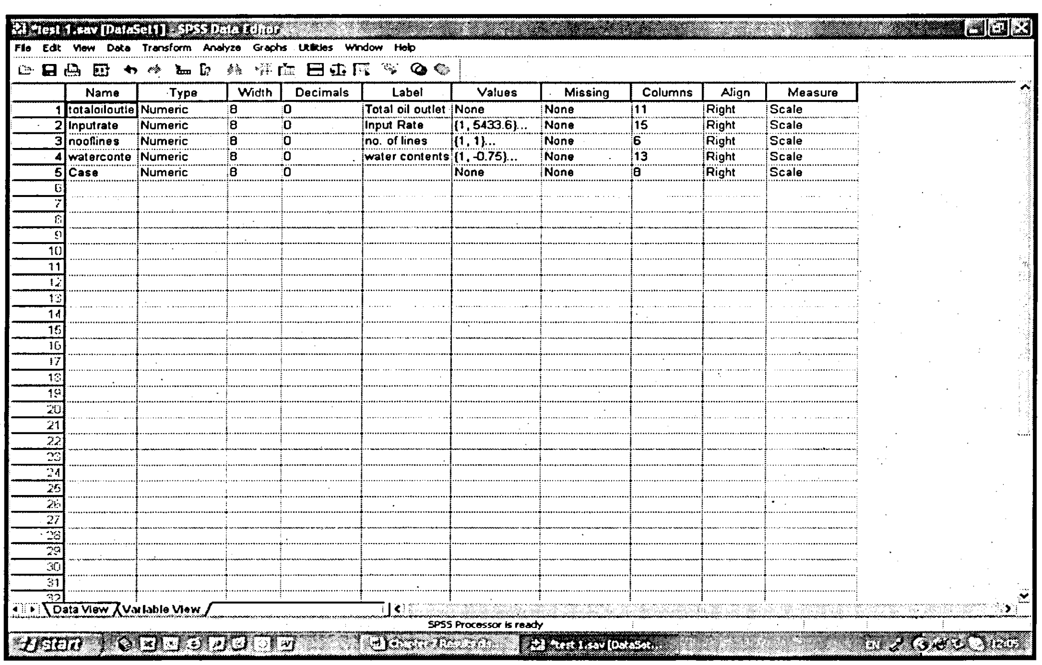
1 : watercontents 1

	totaloiloutlet	Inputrate	nooflines	watercontents	Case
1	912520	5433.6	1	-0.75	1
2	858340	5433.6	1	-0.50	2
3	804150	5433.6	1	-0.25	3
4	749970	5433.6	1	0	4
5	695780	5433.6	1	0.25	5
6	641600	5433.6	1	0.50	6
7	587410	5433.6	1	0.75	7
8	1825000	5433.6	2	-0.75	8
9	1716700	5433.6	2	-0.50	9
10	1608300	5433.6	2	-0.25	10
11	1499900	5433.6	2	0	11
12	1391600	5433.6	2	0.25	12
13	1283200	5433.6	2	0.50	13
14	1174800	5433.6	2	0.75	14
15	2737520	5433.6	3	-0.75	15
16	2575040	5433.6	3	-0.50	16
17	2412450	5433.6	3	-0.25	17
18	2249870	5433.6	3	0	18
19	2087380	5433.6	3	0.25	19
20	1924800	5433.6	3	0.50	20
21	1762210	5433.6	3	0.75	21
22	3650000	5433.6	4	-0.75	22
23	3433400	5433.6	4	-0.50	23
24	3216600	5433.6	4	-0.25	24
25	2999800	5433.6	4	0	25
26	2783200	5433.6	4	0.25	26
27	2566400	5433.6	4	0.50	27
28	2349600	5433.6	4	0.75	28
29	1216700	7244.8	1	-0.75	29
30	1144400	7244.8	1	-0.50	30
31	1072200	7244.8	1	-0.25	31

Data View / Variable View

SPSS Processor is ready

Figure 7.13 Snap-shot of the SPSS Data-view Sheet


*test 1.sav [DataSet1] - SPSS Data Editor

File Edit View Data Transform Analyze Graphs Utilities Window Help

	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure
1	totaloiloutle	Numeric	8	0	Total oil outlet	None	None	11	Right	Scale
2	Inputrate	Numeric	8	0	Input Rate	{1, 5433.6}...	None	15	Right	Scale
3	nooflines	Numeric	8	0	no. of lines	{1, 1}...	None	6	Right	Scale
4	waterconte	Numeric	8	0	water contents	{1, -0.75}...	None	13	Right	Scale
5	Case	Numeric	8	0		None	None	8	Right	Scale

Data View / Variable View

SPSS Processor is ready

Figure 7.14 Snap-shot of the SPSS Variable-view Sheet

The statistical analysis shown in table 7.1 demonstrated that the P-value for all the factors under investigation is zero. This means that the performance-measure considered (the oil-output) is influenced by all of them but to a different degree. For example, it was strongly influenced by the input-rate and number of lines and moderately influenced by the water-content and the interaction between the input-rate & number of lines, and input-rate & water-content. Oil-output was slightly influenced by the interaction between number of lines & water-content. This can be clearly understood by the value of F.

Table 7.1 Output of Univariate Analysis of Variance

Dependent Variable: Total Oil-output

Source	Type III Sum of Squares	df	Mean Square	F- value	Sig.* (P-value)
Corrected Model	1033876566302456.000(a)	57	18138185373727.310	253.823	.000
Intercept	1708836253209632.000	1	1708836253209632.000	23913.210	.000
Input rate	533161025839686.000	3	177720341946562.000	2486.993	.000
Number of lines	341767125647373.400	3	113922375215791.100	1594.213	.000
Water contents	34424083501343.080	6	5737347250223.840	80.288	.000
Input rate * no. of lines	106631670196257.100	9	11847963355139.680	165.799	.000
Input rate * water contents	10415875128914.290	18	578659729384.128	8.098	.000
No. of lines * water contents	7476785985128.580	18	415376999173.811	5.813	.000
Error	3858836115086.129	54	71459928057.151		
Total	2746571655627200.000	112			
Corrected Total	1037735402417543.000	111			

* Confidence level at 95%

α=0.05

This set of figures clearly indicated that the performance-measure (oil-output) was affected by the input-rate, number of lines and water-content. As can been seen, the output increases with the input-rate increase. Undoubtedly, the number of lines has a big impact on the output which is expected. The only difference between this set of figures (7.15-7.21) was the water-content which moderately affected the output.

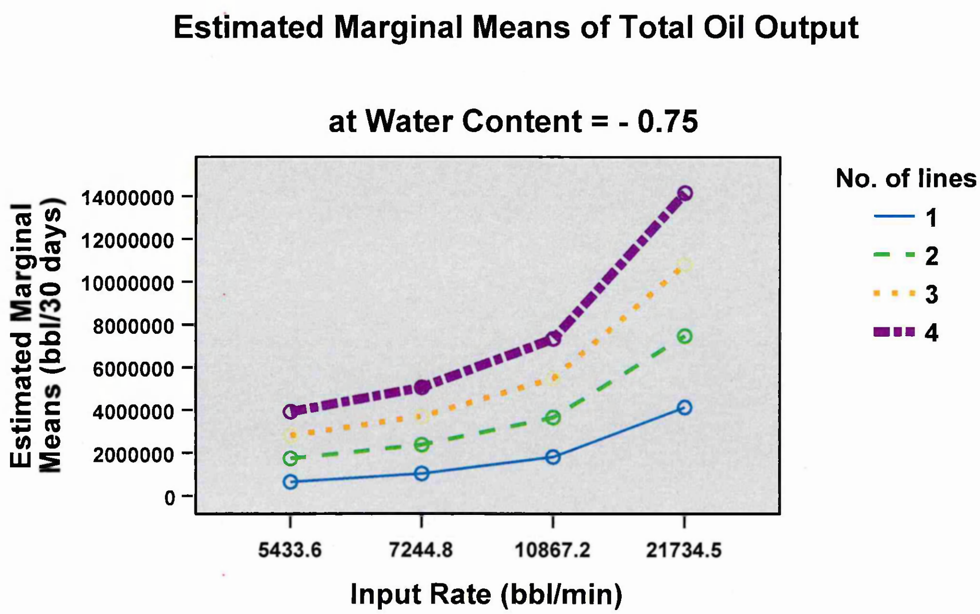


Figure 7.15 Estimated Marginal Means of Total Oil out-put at Water-content -0.75

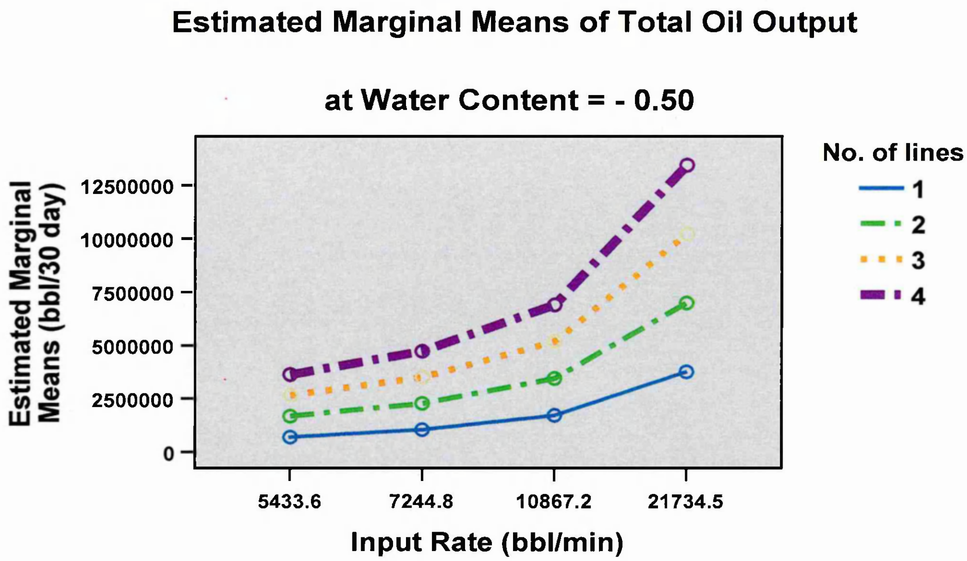


Figure 7.16 Estimated Marginal Means of Total Oil out-put at Water-content -0.50

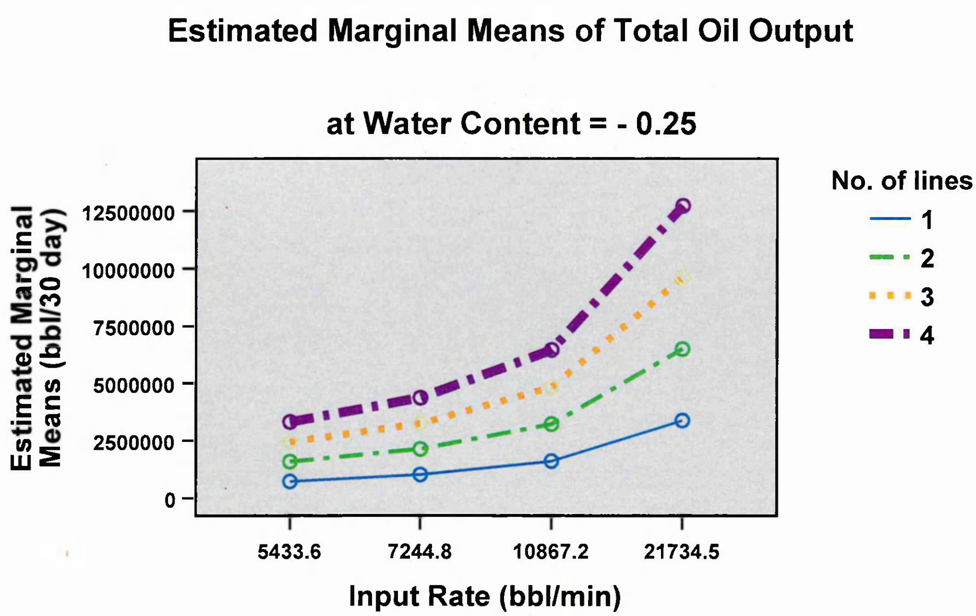


Figure 7.17 Estimated Marginal Means of Total Oil out-put at Water-content - 0.25

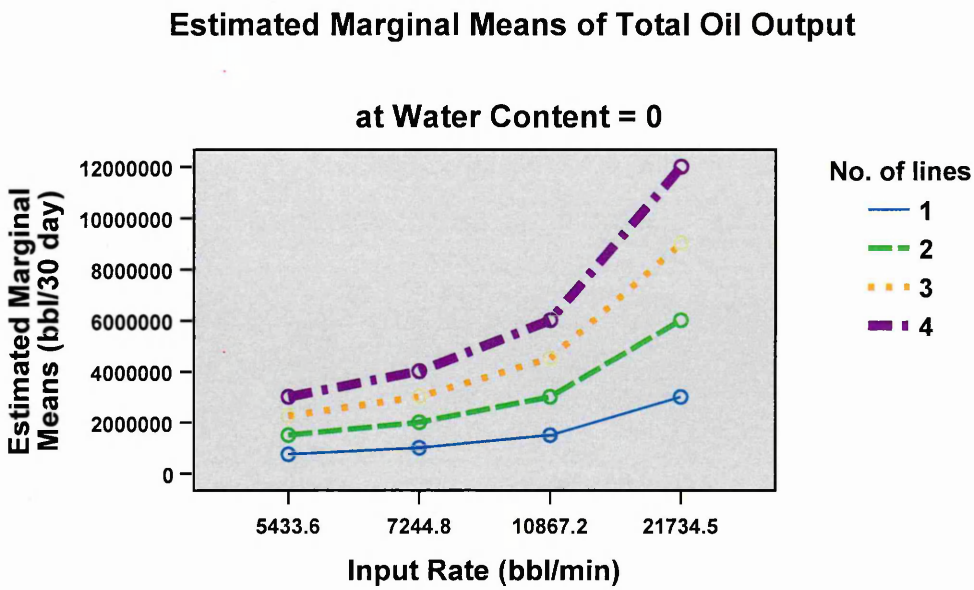


Figure 7.18 Estimated Marginal Means of Total Oil out-put at Water-content 0.0

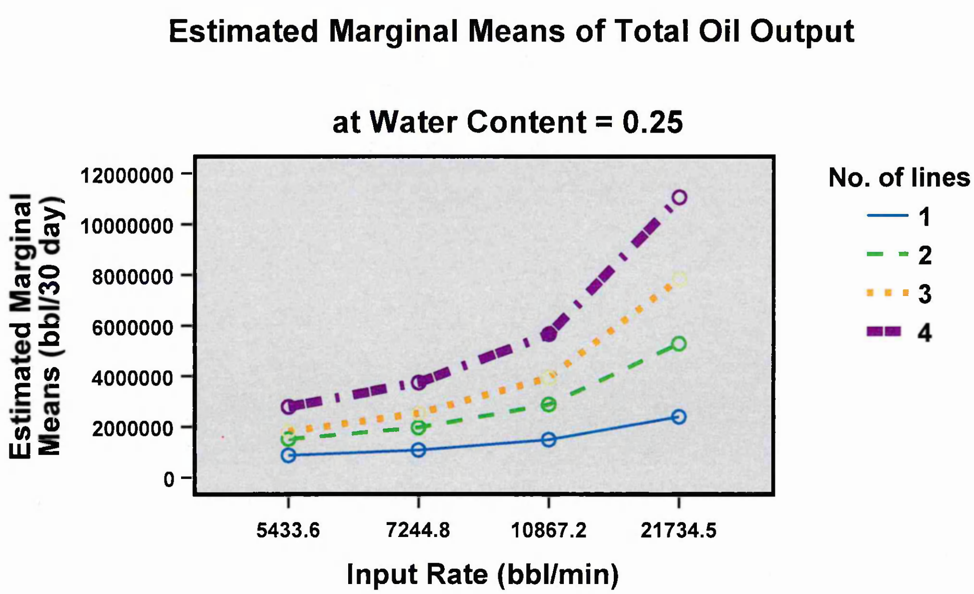


Figure 7.19 Estimated Marginal Means of Total Oil out-put at Water-content 0.25

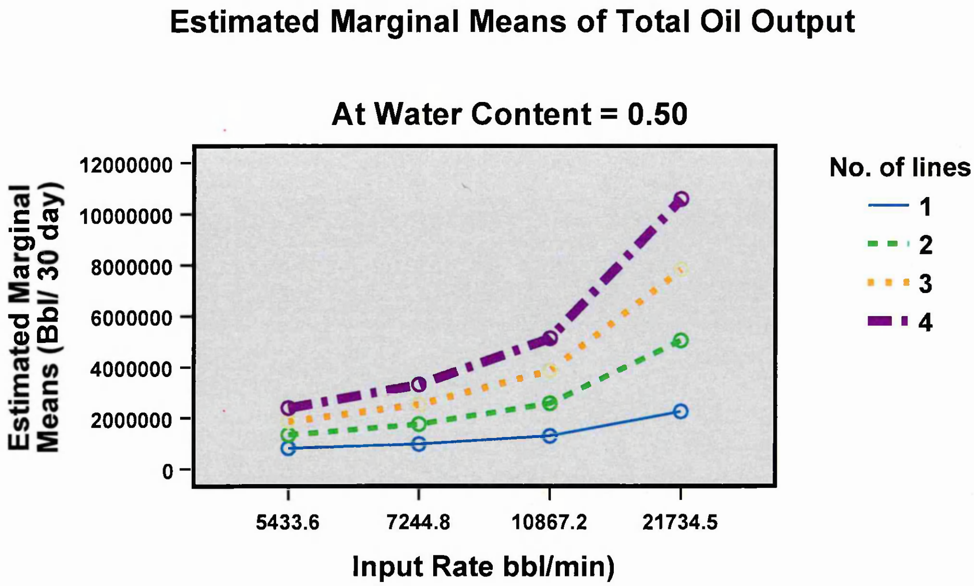


Figure 7.20 Estimated Marginal Means of Total Oil out-put at Water-content 0.50

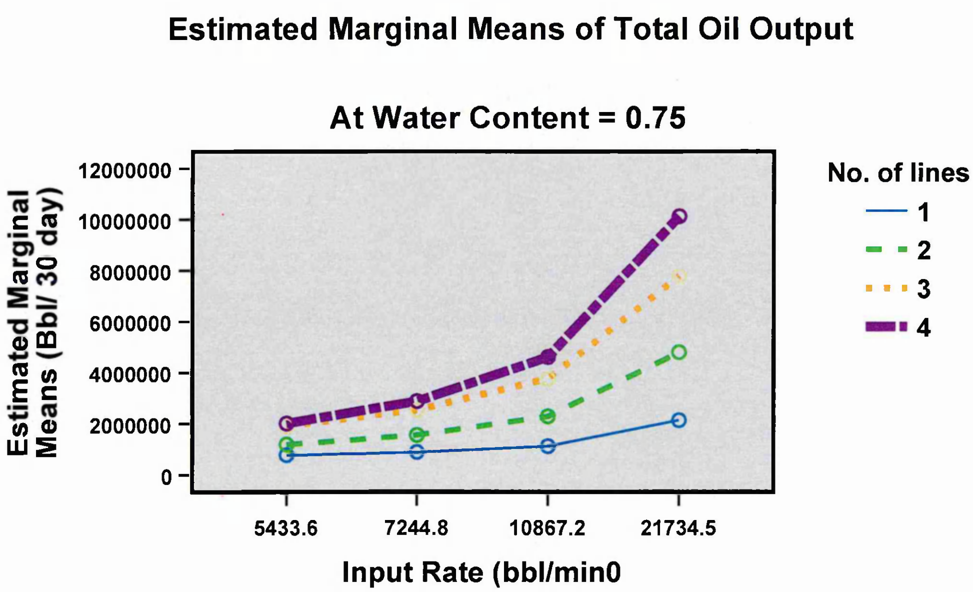
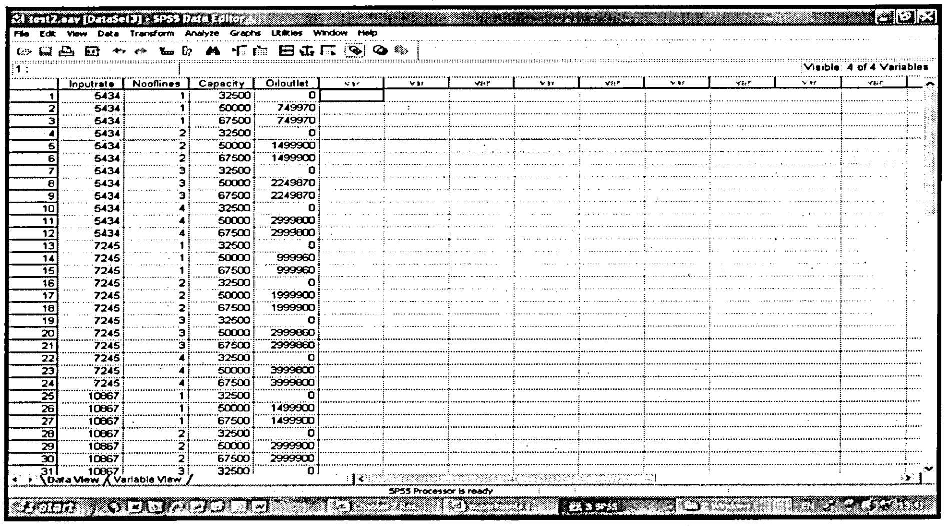


Figure 7.21 Estimated Marginal Means of Total Oil out-put at Water-content 0.75

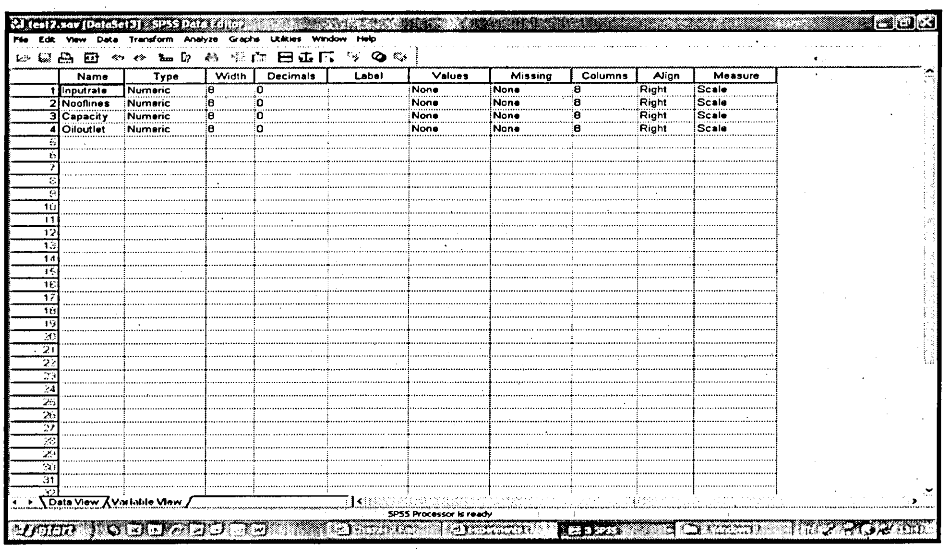
In the second experiment, the effect of the input-rate, number of lines and capacity of the separators was studied. The data were transported to SPSS as shown in figures

7.22 and 7.23 and were analysed by Univariate Analysis of Variance. The results are shown in table 7.2.



	Inputrate	Nooflines	Capacity	Oiloutlet
1	5434	1	32500	0
2	5434	1	50000	749970
3	5434	1	67500	749970
4	5434	2	32500	0
5	5434	2	50000	1499900
6	5434	2	67500	1499900
7	5434	3	32500	0
8	5434	3	50000	2249870
9	5434	3	67500	2249870
10	5434	4	32500	0
11	5434	4	50000	2999800
12	5434	4	67500	2999800
13	7245	1	32500	0
14	7245	1	50000	999960
15	7245	1	67500	999960
16	7245	2	32500	0
17	7245	2	50000	1999900
18	7245	2	67500	1999900
19	7245	3	32500	0
20	7245	3	50000	2999860
21	7245	3	67500	2999860
22	7245	4	32500	0
23	7245	4	50000	3999800
24	7245	4	67500	3999800
25	10867	1	32500	0
26	10867	1	50000	1499900
27	10867	1	67500	1499900
28	10867	2	32500	0
29	10867	2	50000	2999900
30	10867	2	67500	2999900
31	10867	3	32500	0

Figure 7.22 Snap-shot of the SPSS Data-view Sheet



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure
1	Inputrate	Numeric	8	0		None	None	8	Right	Scale
2	Nooflines	Numeric	8	0		None	None	8	Right	Scale
3	Capacity	Numeric	8	0		None	None	8	Right	Scale
4	Oiloutlet	Numeric	8	0		None	None	8	Right	Scale

Figure 7.23 Snap-shot of the SPSS Variable-view Sheet

The results of the performance-measure which were obtained from the analysis are displayed in table 7.2. The P-value for all factors is less than 0.05 which means that the performance-measure is significantly influenced by the factors under investigation and their interactions.

The interaction between the input-rate and the separator-capacity was found with the highest F- value (21.785), followed by the input-rate (14.621), the interaction between the number of lines and capacity (13.965), the interaction between the input-rate and number of lines(11.618), the number of lines (10.395) and finally the capacity with the lowest F- value (7.585).

Table 7.2 Output of Univariate Analysis of Variance

Dependent Variable: Oil Outlput

Source	Type III Sum of Squares	df	Mean Square	F value	Sig.* (p value)
Corrected Model	371514968504 411.500(a)	6	61919161417401.900	35.420	.000
Intercept	108345362311 43.640	1	10834536231143.640	6.198	.017
Input-rate	255586319058 43.840	1	25558631905843.840	14.621	.000
No. Of lines	181712328777 93.110	1	18171232877793.110	10.395	.002
Capacity	132598361926 66.990	1	13259836192666.990	7.585	.009
Input-rate * No. of lines	203104417167 56.480	1	20310441716756.480	11.618	.001
Input-rate * Capacity	380826094462 61.720	1	38082609446261.720	21.785	.000
No. of lines * Capacity	244116719335 22.560	1	24411671933522.560	13.965	.001
Error	716729241599 55.100	41	1748120101462.320		
Total	768678101718 000.000	48			
Corrected Total	443187892664 366.600	47			

* Confidence level at 95%

α=0.05

Graphical presentations of the obtained results are shown in figure 7.24. As can be seen, the input-rate has significant impact on the output as a measure of performance: when the input-rate increases, the output increases accordingly. The same applies with the number of lines. The capacity of the separators also affects the output but the capacity should be decided carefully to gain more production at a logical utilisation without wasting the production-resources. Also, from the figure 7.24, it can be noticed that there will be no benefit from increasing the capacity beyond 50,000 Bbl/day.

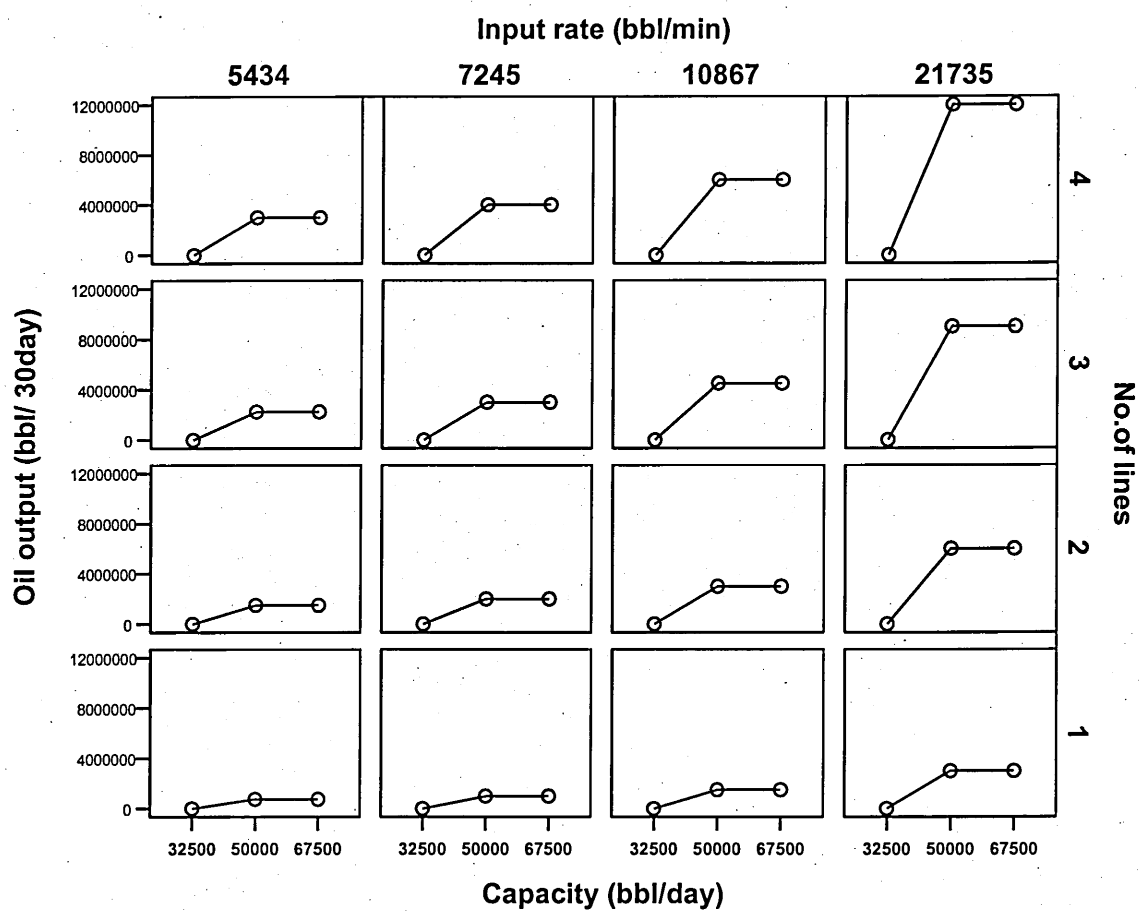


Figure 7.24 Estimated Means of Oil out-put at Different Capacities, Input-rates and Number of lines

7.5 Conclusion

The analysis of the simulation-results obtained from a total of 177 runs through, with different variables at different levels, has been discussed. In these experiments the different factors and levels were studied to explore how these factors affect the performance-measure (oil-output).The results were automatically reported, the output-results for the oil produced were transferred to an Excel file for graphical representation, and SPSS was used to analyse the obtained results.

The next chapter will address the conclusion of the thesis, Contribution to knowledge, Limitation and Further Works

Chapter 8

Conclusions, Contribution to knowledge, Limitation and Further Works

8.1 Conclusion

The development of the developing countries has driven the demand for more energy supplies in production and living. Therefore, the traditional production-management of gas and oil has to be improved in order to cope with the dynamic market-demand. In this study, an integrated framework was developed to optimise crude oil production area which includes oil wells area and production area. The framework mainly integrates two main stages the oil wells area and the oil production area and formed two main parts, which covered briefly as follows:

In the first part of this study mathematical-programming was used to optimise the transportation-cost of the crude oil from the oil wells to the manifold. The problem was modelled by using linear-programming and solved by Lingo/Lindo software. Different scenarios were studied to decide on the most suitable operational-policy to the oil-wells and this depended on supply, demand, quality and the distance between wells and the manifold.

The transportation-cost from the oil-wells to the manifold has been minimised in terms of distance. In the case where supply is greater than the demand, the travelling distance is minimised by avoiding the farthest oil-wells from the manifold.

A dummy-solution was applied in the case where demand is greater than the supply, or when the supply is greater than the demand. The dummy was applied to make a balance between the supply and the demand.

Cost-reduction is a major benefit for using simulation, instead of having real implementation, for testing out the plans or design in the crude oil separation-system without building up or taking out any facilities.

In the second part of the research, simulation-modelling was used to investigate how productivity and profitability can be improved as well as the decision-making in oil-production. A certain numbers of factors were chosen as parameters in the experimental testing using the simulation-model which was developed to study the effect of these parameters on the system's performance.

Simplification would not be something uncommon in any kind of modelling. Some of the factors and processes have been simplified in the proposed model because of the scarcity of the data required.

Data were collected and logical assumptions were made in order to carry on with the simulation-model design. Assumptions were made at a certain level that met the need for reliability as a representation of the real system. The proposed simulation-model drawn in the process flow-chart was constructed by using the ARENA simulation-tool. VBA language was used to enhance the user-interface for ease of use by users. The logic equation sets in the modules enabled the selection of different storage-tanks and the selection of different routes for the entities created. Verification of the model was carried out using a walk-through approach which proved that the model was functioning as expected. The only difficulty was the validation of the model due to lack of data and unavailability of similar models in the literature because the model is consider as continuous simulation. There are not many researchers working in this field and most of them are working in discrete-simulation. However, the results shown were very close to the assumed data; and simulation-experts examined the model and from their point of view the model would perform quite closely to the real system. Therefore, and based on these two stages of the verification and validation, the researcher was confident with the performance of model built.

The model was tested through 177 experimental runs to find out the impact from the interactions between each factor on the output-results. The results shown proved that the crude oil input-rate, number of production-lines, separator-capacity and crude oil quality would have obvious impacts on the output. However, the crude oil input-rate has a very close relationship with SP capacity, and both of them should match each other for balance-point, since if the input is more than the system could afford to process, it would end up in failure. Besides, the imbalance between the input-rate and separator-capacity indicated the utilisation of separator, either too much or too little not giving best results. Since under-utilisation would means lower profitability while over-utilisation would cause system-failure.

8.2 Contribution to knowledge

- The integrated framework developed in this thesis is a major contribution to knowledge due the nature of handling the two main stages of oil filed namely; oil wells area and oil production area for optimisation purposes.

- The mathematical model can be considered as a systematic tool for the company to improve the speed of decision-making and also give them a chance to make an important selection between the wells in the case of a huge oil-field which contains a large number of oil-wells, as in the case-study used in this thesis. This gives real significance to this study.

- Simulation-modelling was used to investigate how productivity and profitability can be improved as well as the decision-making in oil-production. A certain numbers of factors were chosen as parameters in the experimental testing using the simulation-model which was developed to study the effect of these parameters on the system's performance.

- Production-planning is important for understanding what the average production demanded over years will be, and checking if the supply of crude oil would be enough for these demands. However, this might be difficult to justify especially in the 21st century dynamic market, where demand can fluctuate wildly.

- Practitioners able to make alterations to the simulation-design to check the estimated output and enhance the decision-making process quicker so as understanding how the problems might arise within the system and what could be done to solve those problems.

- The animation designed based on the modelled system provides the users with a clear overview on what is happening throughout the process for better understanding and confident in planning and decision making without taking risk of unworkable solutions.

8.3 Limitation and Further Works

- This study is applied in an onshore oilfield; there is a need to investigate what is the possibility of using this study in offshore oilfields where the cost of transportation is more costly than in an onshore oilfield.

- The crude oil transportation-model can be improved by including more factors such as the quality of crude oil, especially when more than one reservoir is used.

- Lingo/ Lindo were used to implement the transportation-model. However, VBA can be used to provide a user-friendly interface to allow non-expert users to choose the different scenarios for the oil-wells' selection which depends on the capacity of the oil-wells and the demand which is made by the customer; and also this would improve, and increase the speed of, the decision-making.

- There is a need to investigate the crude oil quality for its water-content before production, since the less water there is mixed with it, the more oil-output will be gained.

- The capacity of the separator should be matched with its utilisation. The normal utilisation is around 60 percent to allow reduction and increase of productivity when needed. The capacity should be designed to match up the input from the manifold.

- A simulation-model could be designed with some differentiation equations for better estimation of the output within a range of input-rates instead of specific values set in advance. At the time when the crude oil input-rate is more or less than the utilisation of the separator, the model should be able to handle the entity until the input rate is reduced or increased to re-enter the system without disposing of the entity. This could be achieved by writing the VBA code in the model or by using VBA block in ARENA.

- A framework and model-integration with other application-software like Microsoft Excel could be explored more in order to provide more functions and ease of use to the user through programming.

- Other factors related to the crude oil separation could be included one by one to build up a more advanced modelling to handle various situations only if there are extra resources available.

References

Arnold, K., and Stewart, M., (1999), "Surface Production Operations – Design of Oil-Handling Systems and Facilities", Butterworth-Heinemann, 2nd Edition.

Aloise, D., J., Aloise, D., Rocha, T., M., C., Ribeiro C., C., Filho, J., C., Moura, L., S., S., (2006),"Scheduling workover rigs for onshore oil production", *Discrete Applied Mathematics,* Vol.154, pp.695-702.

Bagci, E., Ozcelik, B., (2006), "Analysis of temperature changes on the twist drill under different drilling conditions based on Taguchi method during dry drilling of Al 7075-T651",*International Journal Advanced Manufacturing Technology*, Vol. 29, pp. 629-636.

Ballintuni, K., (1993), "Optimization in Refinery Scheduling: Modelling and Solution", John Weley &sons Ltd, pp. 191-199.

Carvalho, P., M., Minami, K. and Rosa, E., S., (1996), "A dynamic Simulation of a Sub Sea Separation and Boosting System for Offshore Petroleum Production", *SPEA*, Annual technical conference& Exhibition held in Denver, USA, pp. 471-478.

Checkland, P., (1981), "Systems Thinking, Systems Practice", Chichester, UK: Wiley.

Chen, M. and Wang, W., (1997), "A linear Programming Model for Integrated Steel Production and Distribution Planning", *International Journal of Operations & Production Management*, Vol. 17, No.6, pp.592-610.

Cheng, L., and Duran, M., A., (2004), "Logistics for world-wide crude oil transportation using discrete event simulation and optimal control", *Computer and Chemical Engineering* Vol. 28, pp.897-911.

Constant-machado, H., Leclerc, J., Avilan, E., Landaeta G., Anorga, N. and Capote, O., (2005), "Flow modeling of a battery of industrial crude oil/gas separators using ^{113m}In tracer experiments", *Chemical Engineering and Processing* Vol.44, pp. 760-765.

Chung, C., A., (2004), "Simulation Modelling Handbook: A Practical Approach", CRC Press LLC.

Coyle, R.G, (1996), "System Dynamics modelling: A Practical Approach", London: Chapman & Hall.

Coulson, J.M and Richardson, J. F., (1999), "Coulson and Richardson's Chemical Engineering". Vol. 1, Fluid flow, heat transfer and mass transfer, Butterworth-Heinemann, 6th Edition.

COMPACT, Horizontal Conventional Mist Pad Separators, *Compact*, last updated 12 April 2004, [online]. Last accessed on 31 March 2008 at http://www.telusplanet.net/public/compact/products/horizsep.html

COMPACT, Vertical Conventional Mist Pad Separators, *Compact*, last updated 12 April 2004, [online]. Last accessed on 31 March 2008 at http://www.telusplanet.net/public/compact/products/vertsep.html

Davis, P.K, (1992), "Generalizing concepts of verification, validation and accreditation (VV&A) for military simulation", R-4249-ACQ, October 1992, *RAND,* Santa Monica, CA.

Dong. M. (2003)," Inventory Planning of Supply Chains by Linking Production authorisation Strategy to Queuing Models" *Production Planning & Control*, Vol. 14, No. 6, PP. 533-541.

EIA, (2006), "Country Energy Profiles", *Energy Information Administration - Official Energy Statistic from the U.S. Government* at: http://tonto.eia.doe.gov/country/index.cfm

EIA, (2006), Country Energy Profiles, *Energy Information Administration - Official Energy Statistic from the U.S. Government*, [online]. Last accessed on 31 March 2008 at http://tonto.eia.doe.gov/country/index.cfm)

Eni, (2006), "Company Profile", *Eni Spa*, [online]. Last accessed on 20 June 2006 at http://www.eni.it/en_IT/company/company-profile/company-profile.shtml

Farago, I., Georgiev, K., Thomsen, P., G. and Zlatev, Z., (2007), "Numerical and computational issues related to applied mathematical modelling," *Elsevier Inc.* [Online]. Last accessed on 09 May 2008 at: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TYC-4P59XFG-1&_user=126038&_coverDate=08%2F31%2F2008&_rdoc=2&_fmt=high&_orig=browse&_srch=doc-info(%23toc%235615%232008%23999679991%23686655%23FLA%23display%23Volume)&_cdi=5615&_sort=d&_docanchor=&_ct=14&_acct=C000010260&_version=1&_urlVersion=0&_userid=126038&md5=b552c0f3781d6fa5830ab82297627900

Fichter, D., P., (2000), "Application of Genetic Algorithms in Portfolio Optimisation for the Oil and Gas Industry", *Society of Petroleum Engineers SPE*, Annual Technical Conference and Exhibition held in Dallas, Texas, pp. 269-276.

Fraedrich, D. and Goldberg, A., (2000), "A methodological Framework for the Validation of Predictive Simulations", *European Journal of Operational Research*, Vol.124, pp. 55-62.

Giersbrecht, F.G. and Gumpertz, L., M, (2004), "Planning, Construction, and Statistical Analysis of Comparative Experiments", Hoboken, NJ: Wiley.

Giliberti, S., Erba, M., Rampoldi, M., and Saad, A., (1995), "Optimisation of the Numerical Simulation in a Giant Oil field by up Scaling of relative Permeability Curves", *International meeting on Petroleum Engineering*, Vol.1, pp.413-425.

Ghoniem, E. O., Samizo, N. Al-Thuwainy, A., (2005)," Successful Application of Production Optimisation Models to Sustain Field Target and to Defer Capital Investment in Offshore Khafji Field", *Society of Petroleum Engineers Inc. SPE*, Middle East Oil &Gas show and Conference held in Bahrin International Exhibition centre.

Gothe-lundgren, M., Lundgren, J. T., and Persson, J. A., (2002), "An Optimization Model for Refinery Production Scheduling ", *International Journal of Production Economics*, Vol.78, pp. 255-270.

Hallanger, A, Michelsen, C., Soenstaboe, F, Norway, E., Knutsen, T and Hydro, N., (1996), "A Simulation Model for Three-Phase Gravity Separators", *Society of Petroleum Engineers Inc.*

Hansen, E.W.M., (2001), "Phenomenological Modelling and Simulation of fluid flow and Separation behaviour in Offshore Gravity Separators", *American Society of Mechanical Engineers, Structure and Fluid*, Vol.431, pp. 23-29.

Jacinto, C., M., C., (2002), "Energy production and trading: discrete event simulation for the risk of development of an oil field," *Winter Simulation Conference,* pp. 1588–1592. [Online]. Last accessed on 1 May 2008 at: http://delivery.acm.org.lcproxy.shu.ac.uk/10.1145/1040000/1030685/p1588-jacinto.pdf?key1=1030685&key2=5228669021&coll=GUIDE&dl=GUIDE&CFID=26192770&CFTOKEN=76461200

Jalali, Y., Wassenhove, W. V., Romano, C., and Pickles, R., (1997), "On-line process Optimization in a North sea field", *Annual technical conference& Exhibition*, pp. 727-734.

Kelton, W., D., Sadowski, R., P .and Sturrock, D., T., (2007), "Simulation with Arena", Fourth Edition, Mc Graw-Hill Companies, Inc.

Kinnear, P., R. and Gray, C., D., (2008), "SPSS 15 Made Simple", Psychology Press.

Khang, N., T., Bich, H. V., Son, T. C., Hoe, L. D. and Thuc, P. D., (2004), "A new Approach for Regime Optimisation of Oil and Gas Mixture Pipeline Transportation", *Society of Petroleum Engineers Inc. SPE, Asia Pacific oil and gas conference and Exhibition held in Perth, Australia*, pp. 1187-1193.

Kokal, S., and Al-ghamdi, A., (2005), "Oil-Water Separation Experience from a Large Oil Field", *Society of Petroleum Engineers Inc.SPE*, Middle East Oil &Gas show and Conference held in Bahrin International Exhibition Centre.

Langley, P., A. and Morecroft, J., D. W., (2003), "Performance and learning in a simulation of oil industry dynamics," *Elsevier B.V.* 11 March 2003, [Online]. Last accessed on 1 May 2008 at:

http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6VCT-4840XKV-5-

2Y&_cdi=5963&_user=126038&_orig=search&_coverDate=06%2F16%2F2004&_s

k=998449996&view=c&wchp=dGLbVtz-zSkWz&md5=bf024be4da585ca1d8571c5dd5c3a929&ie=/sdarticle.pdf

Li, P., Gracia, H. A. and Wozny, G., (1998), "Optimisation of a Semibatch Distillation Process with Model Validation on the Industrial Site", *Industrial Engineering Chemistry Research*, Vol. 37, pp. 1341-1350.

Li, W., Hui, C. W., Hua, B. and Tong, Z., (2002)," Scheduling Crude Oil Unloading, Storage, and Processing", *Industrial Engineering Chemistry Research*, Vol. 41, PP. 6723-6734.

Lingo user's guide (2004), Lindo Systems INC.

Lopez-vazquez, C. M, and Fall, C., (2004), "Improvement of a Gravity Oil Separator Using A Designed Experiment", *Water, Air, and Soil Pollution,* Vol.157, PP. 33-52.

Maki, D. and Thompson, M., (2006), "Mathematical Modelling and Computer Simulation", Thomson Brooks/Cole.

Mueller, J.P, (2007), "VBA for Dummies", Wiley Publishing, Inc., 5th Edition.

Neelamkavil, F., (1987), "Computer Simulation and Modelling", John Wiley & Sons Ltd.

Olea, E. S., Romero, N. M., (1998), "Anew Methodology to Determine the Optimal Pressure of the stage in the Separation Oil-Gas." SPE International petroleum conference exhibition at Mexico held in VillaHermosa, Mexico, PP. 243-247.

Pettersson, F., and Soderman, J., (2005), "Structural and Operational Optimisation of Distributed Energy Systems", *Applied Thermal Engineering*, Vol. 26, pp. 1400-1408.

Pisarenko, E. V. and Pisarenko, V. N. (2006), "Analysis and Modeling of Synthesis Gas Conversion to Methanol: New Trends toward Increasing Methanol Production Profitability," *Pleiades Publishing, Ltd.* [Online]. Last accessed on 28 April 2008 at: http://www.springerlink.com.lcproxy.shu.ac.uk/content/e477t3v0870782v1/fulltext.pdf

Rincon, G., Alvarez, M., Perez, M., and Hernandez, S. (2005), "A discrete-event Simulation and Continuous Software Evaluation on A system Quality Model: An Oil Industry Case", *Information &Management,* Vol. 42, pp.1051-1066.

Robinson S., (2003), "Simulation: The Practice of Model Development and Use". John Wiley & Sons LTD.

Robinson S., (2004), "Simulation: The Practice of Model Development and Use". John Wiley & Sons LTD.

Robinson S., (1994), "Successful Simulation, A practical to Simulation Projects", McGraw-Hill .

Sayda, A., F and Taylor, J., H., (2007), "Modeling and Control of Three-Phase Gravity Separators in Oil Production Facilities," *Prac. American Control Conference*, New York, 11-13 July 2007. [Online]. Last accessed on 1 May 2008 at: http://www.ee.unb.ca/jtaylor/Publications/acc07_pilot.pdf

Schrage, L., (2002), "Optimisation Modelling with Lingo", Lindo System Inc USA, 5th Edition.

Shah, N., (1996), "Mathematical programming techniques for crude oil scheduling", *Computers Chemical Engineering*, Vol. 20, pp. 1227-1232.

Sinnott, R. K, (1999), "Coulson & Richardson's Chemical Engineering", Butterworth-Heinemann, 3rd Edition.

Sinha, S., P, Al-kandar, I., and Al-anezi, K., (2006), "Using An Integrated Approach to Production Optimization in A Mature Field: Burgan Field", *Search and Discovery Article 40183,* January 12, 2006. [Online]. Last accessed on 1 May 2008 at: http://www.searchanddiscovery.net/documents/2006/06001sinha/images/sinha.pdf

Taha, H., A., (2003), "Operations Research an Introduction", Seventh Edition, Pearson Education, Inc.

Taal, M. and Wortmann, J. C., (1997), "Integrating MRP and finite Capacity Planning," *Production Planning &Control*, Vol. 8, No. 3, pp. 245-254.

The British Petroleum Company Limited, (1977), "*Our Industry Petroleum",* The British Petroleum Company Limited.

Tavares, M. E. E., Szklo, A. S., Machado, G. V., Schaeffer, R., Mariano, J. B., and Sala, J. F. (2006), "Oil Refining Expansion Criteria for Brazil", *Energy Policy*, Vol. 34, pp.3027-3040.

Taha, H., A., (2003), "Operations Research an Introduction", Seventh Edition, Pearson Education, Inc.

Wang, H., Yin, W., Yang, W. Q and Beck, M. S, (1996), "Optimum design of segmented capacitance sensing array for multi-phase interface measurement," *Meas. Sci. Techno,* Issue 1, January 1996. [Online]. Last accessed on 28 April at: http://www.iop.org.lcproxy.shu.ac.uk/EJ/article/0957-0233/7/1/011/e60110.pdf?request-id=9dc798f3-f048-49c4-8c01-bfb98a5d01bd,

Williams, H. P., (1999), "Model Building in Mathematical Programming", Fourth Edition, John Wiley& Sons Ltd.

Winston, W., (2004),"Operations Research", Thomson Brooks/COLE.

Xu, Xiao-xuan, (2005), "Study on oil–water two-phase flow in horizontal pipelines," *Science Direct*, 7 March 2007. [Online]. Last accessed on 1 May 2008 at: http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6VDW-4NBBYT5-1-K&_cdi=5993&_user=126038&_orig=search&_coverDate=10%2F31%2F2007&_sk=999409998&view=c&wchp=dGLzVzz-zSkWz&md5=000234b0780b75247119f4b727ed6c59&ie=/sdarticle.pdf

Yamamoto, I., Matsuura, M., and Hirayama, H., (2000),"Total Optimisation Offshore Oil Production Simulator Based on Discrete Event Modelling and Control Theory", Manoeuvring and Control of Marine Craft, Aalborg, Denmark.

Yu, W., Rubio, J.D. J., and Morales, A, (2004), "Optimisation of Crude Oil Blending with Neural Networks", *Electrical and Electronics Engineers Inc. Spons: IEEE Control System Society*, pp. 4903-4908.

Yueming, C. and Halijum, F., (1998), "Optimal Combination of Stabilizing Measures for Oilfield Production", *Journal of the University of Petroleum*, China, Vol.22, No. 2, pp. 33-34.

Appendix A

Oil Wells Mathematical Optimisation Model

Figure 1 Lingo Out-put when Supply Equal the Demand

```
Global optimal solution found.
   Objective value:                          0.7642677E+09
   Total solver iterations:                              0
```

Section 1:-

Variable	Value	Reduced Cost
CAPACITY(A1)	6719.000	0.000000
CAPACITY(A3)	24321.00	0.000000
CAPACITY(A4)	12546.00	0.000000
CAPACITY(A7)	6711.000	0.000000
CAPACITY(A8)	10606.00	0.000000
CAPACITY(A11)	782.0000	0.000000
CAPACITY(A13)	9896.000	0.000000
CAPACITY(A14)	2944.000	0.000000
CAPACITY(A15)	10951.00	0.000000
CAPACITY(A16)	6287.000	0.000000
CAPACITY(A17)	14606.00	0.000000
CAPACITY(A19)	9944.000	0.000000
CAPACITY(A20)	8411.000	0.000000
CAPACITY(A21)	8646.000	0.000000
CAPACITY(A22)	12263.00	0.000000
CAPACITY(A24)	4262.000	0.000000
CAPACITY(A25)	11475.00	0.000000
CAPACITY(A27)	4311.000	0.000000
CAPACITY(A28)	6422.000	0.000000
CAPACITY(A29)	7952.000	0.000000
CAPACITY(A31)	6192.000	0.000000
CAPACITY(A38)	5020.000	0.000000
CAPACITY(A39)	2212.000	0.000000
CAPACITY(A41)	6938.000	0.000000
CAPACITY(A42)	4109.000	0.000000
CAPACITY(A46)	3722.000	0.000000
CAPACITY(A50)	4374.000	0.000000
CAPACITY(A52)	3223.000	0.000000
CAPACITY(A53)	5492.000	0.000000
CAPACITY(A54)	3180.000	0.000000
CAPACITY(A55)	7207.000	0.000000
CAPACITY(A56)	3700.000	0.000000
CAPACITY(A57)	3696.000	0.000000
CAPACITY(A58)	4228.000	0.000000
CAPACITY(A60)	21304.00	0.000000
CAPACITY(A61)	3759.000	0.000000
CAPACITY(A62)	3784.000	0.000000
CAPACITY(A63)	5642.000	0.000000
CAPACITY(A64)	6510.000	0.000000
CAPACITY(A66)	8009.000	0.000000
CAPACITY(A67)	4972.000	0.000000
CAPACITY(A68)	2771.000	0.000000
CAPACITY(A69)	2324.000	0.000000
CAPACITY(A70)	7448.000	0.000000
CAPACITY(A71)	5438.000	0.000000
CAPACITY(A75)	8195.000	0.000000
CAPACITY(A78)	2417.000	0.000000
CAPACITY(A80)	9259.000	0.000000
CAPACITY(A82)	2552.000	0.000000

CAPACITY(A83)	7115.000	0.000000

Section 2:- **DEMAND(M1)** **349919.0** **0.000000**

Section 3:-

DISTANCE(A1, M1)	220.0000	0.000000
DISTANCE(A3, M1)	100.0000	0.000000
DISTANCE(A4, M1)	3500.000	0.000000
DISTANCE(A7, M1)	55.00000	0.000000
DISTANCE(A8, M1)	2118.000	0.000000
DISTANCE(A11, M1)	3150.000	0.000000
DISTANCE(A13, M1)	6300.000	0.000000
DISTANCE(A14, M1)	100.0000	0.000000
DISTANCE(A15, M1)	2850.000	0.000000
DISTANCE(A16, M1)	2350.000	0.000000
DISTANCE(A17, M1)	4100.000	0.000000
DISTANCE(A19, M1)	100.0000	0.000000
DISTANCE(A20, M1)	4400.000	0.000000
DISTANCE(A21, M1)	60.00000	0.000000
DISTANCE(A22, M1)	2100.000	0.000000
DISTANCE(A24, M1)	1550.000	0.000000
DISTANCE(A25, M1)	1560.000	0.000000
DISTANCE(A27, M1)	1300.000	0.000000
DISTANCE(A28, M1)	930.0000	0.000000
DISTANCE(A29, M1)	1600.000	0.000000
DISTANCE(A30, M1)	1000.000	0.000000
DISTANCE(A31, M1)	3000.000	0.000000
DISTANCE(A38, M1)	1200.000	0.000000
DISTANCE(A39, M1)	1900.000	0.000000
DISTANCE(A41, M1)	50.00000	0.000000
DISTANCE(A42, M1)	50.00000	0.000000
DISTANCE(A46, M1)	1300.000	0.000000
DISTANCE(A50, M1)	4500.000	0.000000
DISTANCE(A52, M1)	3300.000	0.000000
DISTANCE(A53, M1)	3500.000	0.000000
DISTANCE(A54, M1)	1900.000	0.000000
DISTANCE(A55, M1)	3700.000	0.000000
DISTANCE(A56, M1)	1300.000	0.000000
DISTANCE(A57, M1)	2000.000	0.000000
DISTANCE(A58, M1)	5900.000	0.000000
DISTANCE(A60, M1)	2000.000	0.000000
DISTANCE(A61, M1)	4500.000	0.000000
DISTANCE(A62, M1)	3000.000	0.000000
DISTANCE(A63, M1)	4000.000	0.000000
DISTANCE(A64, M1)	2200.000	0.000000
DISTANCE(A66, M1)	3000.000	0.000000
DISTANCE(A67, M1)	1200.000	0.000000
DISTANCE(A68, M1)	200.0000	0.000000
DISTANCE(A69, M1)	3700.000	0.000000
DISTANCE(A70, M1)	1000.000	0.000000
DISTANCE(A71, M1)	4000.000	0.000000
DISTANCE(A75, M1)	900.0000	0.000000
DISTANCE(A78, M1)	400.0000	0.000000
DISTANCE(A80, M1)	3000.000	0.000000
DISTANCE(A82, M1)	4000.000	0.000000
DISTANCE(A83, M1)	4000.000	0.000000

Section4:-

BARREL(A1, M1)	6719.000	0.000000
BARREL(A3, M1)	24321.00	0.000000
BARREL(A4, M1)	12546.00	0.000000
BARREL(A7, M1)	6711.000	0.000000

```
BARREL( A8, M1)      10606.00      0.000000
BARREL( A11, M1)     782.0000      0.000000
BARREL( A13, M1)     9896.000      0.000000
BARREL( A14, M1)     2944.000      0.000000
BARREL( A15, M1)     10951.00      0.000000
BARREL( A16, M1)     6287.000      0.000000
BARREL( A17, M1)     14606.00      0.000000
BARREL( A19, M1)     9944.000      0.000000
BARREL( A20, M1)     8411.000      0.000000
BARREL( A21, M1)     8646.000      0.000000
BARREL( A22, M1)     12263.00      0.000000
BARREL( A24, M1)     4262.000      0.000000
BARREL( A25, M1)     11475.00      0.000000
BARREL( A27, M1)     4311.000      0.000000
BARREL( A28, M1)     6422.000      0.000000
BARREL( A29, M1)     7952.000      0.000000
BARREL( A30, M1)     5072.000      0.000000
BARREL( A31, M1)     6192.000      0.000000
BARREL( A38, M1)     5020.000      0.000000
BARREL( A39, M1)     2212.000      0.000000
BARREL( A41, M1)     6938.000      0.000000
BARREL( A42, M1)     4109.000      0.000000
BARREL( A46, M1)     3722.000      0.000000
BARREL( A50, M1)     4374.000      0.000000
BARREL( A52, M1)     3223.000      0.000000
BARREL( A53, M1)     5492.000      0.000000
BARREL( A54, M1)     3180.000      0.000000
BARREL( A55, M1)     7207.000      0.000000
BARREL( A56, M1)     3700.000      0.000000
BARREL( A57, M1)     3696.000      0.000000
BARREL( A58, M1)     4228.000      0.000000
BARREL( A60, M1)     21304.00      0.000000
BARREL( A61, M1)     3759.000      0.000000
BARREL( A62, M1)     3784.000      0.000000
BARREL( A63, M1)     5642.000      0.000000
BARREL( A64, M1)     6510.000      0.000000
BARREL( A66, M1)     8009.000      0.000000
BARREL( A67, M1)     4972.000      0.000000
BARREL( A68, M1)     2771.000      0.000000
BARREL( A69, M1)     2324.000      0.000000
BARREL( A70, M1)     7448.000      0.000000
BARREL( A71, M1)     5438.000      0.000000
BARREL( A75, M1)     8195.000      0.000000
BARREL( A78, M1)     2417.000      0.000000
BARREL( A80, M1)     9259.000      0.000000
BARREL( A82, M1)     2552.000      0.000000
BARREL( A83, M1)     7115.000      0.000000
```

Section 5:-

```
Row   Slack or Surplus    Dual Price
  1     0.7642677E+09     -1.000000


  2      0.000000         -6300.000
  3      0.000000          6080.000
  4      0.000000          6200.000
  5      0.000000          2800.000
  6      0.000000          6245.000
  7      0.000000          4182.000
  8      0.000000          3150.000
  9      0.000000          0.000000
 10      0.000000          6200.000
```

11	0.000000	3450.000
12	0.000000	3950.000
13	0.000000	2200.000
14	0.000000	6200.000
15	0.000000	1900.000
16	0.000000	6240.000
17	0.000000	4200.000
18	0.000000	4750.000
19	0.000000	4740.000
20	0.000000	5000.000
21	0.000000	5370.000
22	0.000000	4700.000
23	0.000000	5300.000
24	0.000000	3300.000
25	0.000000	5100.000
26	0.000000	4400.000
27	0.000000	6250.000
28	0.000000	6250.000
29	0.000000	5000.000
30	0.000000	1800.000
31	0.000000	3000.000
32	0.000000	2800.000
33	0.000000	4400.000
34	0.000000	2600.000
35	0.000000	5000.000
36	0.000000	4300.000
37	0.000000	400.0000
38	0.000000	4300.000
39	0.000000	1800.000
40	0.000000	3300.000
41	0.000000	2300.000
42	0.000000	4100.000
43	0.000000	3300.000
44	0.000000	5100.000
45	0.000000	6100.000
46	0.000000	2600.000
47	0.000000	5300.000
48	0.000000	2300.000
49	0.000000	5400.000
50	0.000000	5900.000
51	0.000000	3300.000
52	0.000000	2300.000
53	0.000000	2300.000

Figure 2 Lindo Out-put when Supply Greater than the Demand

```
Global optimal solution found.
   Objective value:                              0.6509002E+09
   Total solver iterations:                                  3
```

Variable	Value	Reduced Cost
CAPACITY(A1)	6719.000	0.000000
CAPACITY(A3)	24321.00	0.000000
CAPACITY(A4)	12546.00	0.000000
CAPACITY(A7)	6711.000	0.000000
CAPACITY(A8)	10606.00	0.000000
CAPACITY(A11)	782.0000	0.000000
CAPACITY(A13)	9896.000	0.000000
CAPACITY(A14)	2944.000	0.000000
CAPACITY(A15)	10951.00	0.000000
CAPACITY(A16)	6287.000	0.000000
CAPACITY(A17)	14606.00	0.000000
CAPACITY(A19)	9944.000	0.000000
CAPACITY(A20)	8411.000	0.000000
CAPACITY(A21)	8646.000	0.000000
CAPACITY(A22)	12263.00	0.000000
CAPACITY(A24)	4262.000	0.000000
CAPACITY(A25)	11475.00	0.000000
CAPACITY(A27)	4311.000	0.000000
CAPACITY(A28)	6422.000	0.000000
CAPACITY(A29)	7952.000	0.000000
CAPACITY(A30)	5072.000	0.000000
CAPACITY(A31)	6192.000	0.000000
CAPACITY(A38)	5020.000	0.000000
CAPACITY(A39)	2212.000	0.000000
CAPACITY(A41)	6938.000	0.000000
CAPACITY(A42)	4109.000	0.000000
CAPACITY(A46)	3722.000	0.000000
CAPACITY(A50)	4374.000	0.000000
CAPACITY(A52)	3223.000	0.000000
CAPACITY(A53)	5492.000	0.000000
CAPACITY(A54)	3180.000	0.000000
CAPACITY(A55)	7207.000	0.000000
CAPACITY(A56)	3700.000	0.000000
CAPACITY(A57)	3696.000	0.000000
CAPACITY(A58)	4228.000	0.000000
CAPACITY(A60)	21304.00	0.000000
CAPACITY(A61)	3759.000	0.000000
CAPACITY(A62)	3784.000	0.000000
CAPACITY(A63)	5642.000	0.000000
CAPACITY(A64)	6510.000	0.000000
CAPACITY(A66)	8009.000	0.000000
CAPACITY(A67)	4972.000	0.000000
CAPACITY(A68)	2771.000	0.000000
CAPACITY(A69)	2324.000	0.000000
CAPACITY(A70)	7448.000	0.000000
CAPACITY(A71)	5438.000	0.000000
CAPACITY(A75)	8195.000	0.000000
CAPACITY(A78)	2417.000	0.000000
CAPACITY(A80)	9259.000	0.000000

CAPACITY(A82)	2552.000	0.000000
CAPACITY(A83)	7115.000	0.000000
DEMAND(M1)	330000.0	0.000000
DISTANCE(A1, M1)	220.0000	0.000000
DISTANCE(A3, M1)	100.0000	0.000000
DISTANCE(A4, M1)	3500.000	0.000000
DISTANCE(A7, M1)	55.00000	0.000000
DISTANCE(A8, M1)	2118.000	0.000000
DISTANCE(A11, M1)	3150.000	0.000000
DISTANCE(A13, M1)	6300.000	0.000000
DISTANCE(A14, M1)	100.0000	0.000000
DISTANCE(A15, M1)	2850.000	0.000000
DISTANCE(A16, M1)	2350.000	0.000000
DISTANCE(A17, M1)	4100.000	0.000000
DISTANCE(A19, M1)	100.0000	0.000000
DISTANCE(A20, M1)	4400.000	0.000000
DISTANCE(A21, M1)	60.00000	0.000000
DISTANCE(A22, M1)	2100.000	0.000000
DISTANCE(A24, M1)	1550.000	0.000000
DISTANCE(A25, M1)	1560.000	0.000000
DISTANCE(A27, M1)	1300.000	0.000000
DISTANCE(A28, M1)	930.0000	0.000000
DISTANCE(A29, M1)	1600.000	0.000000
DISTANCE(A30, M1)	1000.000	0.000000
DISTANCE(A31, M1)	3000.000	0.000000
DISTANCE(A38, M1)	1200.000	0.000000
DISTANCE(A39, M1)	1900.000	0.000000
DISTANCE(A41, M1)	50.00000	0.000000
DISTANCE(A42, M1)	50.00000	0.000000
DISTANCE(A46, M1)	1300.000	0.000000
DISTANCE(A50, M1)	4500.000	0.000000
DISTANCE(A52, M1)	3300.000	0.000000
DISTANCE(A53, M1)	3500.000	0.000000
DISTANCE(A54, M1)	1900.000	0.000000
DISTANCE(A55, M1)	3700.000	0.000000
DISTANCE(A56, M1)	1300.000	0.000000
DISTANCE(A57, M1)	2000.000	0.000000
DISTANCE(A58, M1)	5900.000	0.000000
DISTANCE(A60, M1)	2000.000	0.000000
DISTANCE(A61, M1)	4500.000	0.000000
DISTANCE(A62, M1)	3000.000	0.000000
DISTANCE(A63, M1)	4000.000	0.000000
DISTANCE(A64, M1)	2200.000	0.000000
DISTANCE(A66, M1)	3000.000	0.000000
DISTANCE(A67, M1)	1200.000	0.000000
DISTANCE(A68, M1)	200.0000	0.000000
DISTANCE(A69, M1)	3700.000	0.000000
DISTANCE(A70, M1)	1000.000	0.000000
DISTANCE(A71, M1)	4000.000	0.000000
DISTANCE(A75, M1)	900.0000	0.000000
DISTANCE(A78, M1)	400.0000	0.000000
DISTANCE(A80, M1)	3000.000	0.000000
DISTANCE(A82, M1)	4000.000	0.000000
DISTANCE(A83, M1)	4000.000	0.000000
BARREL(A1, M1)	6719.000	0.000000
BARREL(A3, M1)	24321.00	0.000000
BARREL(A4, M1)	12546.00	0.000000
BARREL(A7, M1)	6711.000	0.000000
BARREL(A8, M1)	10606.00	0.000000
BARREL(A11, M1)	782.0000	0.000000

BARREL(A13, M1)	0.000000	1800.000
BARREL(A14, M1)	2944.000	0.000000
BARREL(A15, M1)	10951.00	0.000000
BARREL(A16, M1)	6287.000	0.000000
BARREL(A17, M1)	14606.00	0.000000
BARREL(A19, M1)	9944.000	0.000000
BARREL(A20, M1)	8411.000	0.000000
BARREL(A21, M1)	8646.000	0.000000
BARREL(A22, M1)	12263.00	0.000000
BARREL(A24, M1)	4262.000	0.000000
BARREL(A25, M1)	11475.00	0.000000
BARREL(A27, M1)	4311.000	0.000000
BARREL(A28, M1)	6422.000	0.000000
BARREL(A29, M1)	7952.000	0.000000
BARREL(A30, M1)	5072.000	0.000000
BARREL(A31, M1)	6192.000	0.000000
BARREL(A38, M1)	5020.000	0.000000
BARREL(A39, M1)	2212.000	0.000000
BARREL(A41, M1)	6938.000	0.000000
BARREL(A42, M1)	4109.000	0.000000
BARREL(A46, M1)	3722.000	0.000000
BARREL(A50, M1)	0.000000	0.000000
BARREL(A52, M1)	3223.000	0.000000
BARREL(A53, M1)	5492.000	0.000000
BARREL(A54, M1)	3180.000	0.000000
BARREL(A55, M1)	7207.000	0.000000
BARREL(A56, M1)	3700.000	0.000000
BARREL(A57, M1)	3696.000	0.000000
BARREL(A58, M1)	0.000000	1400.000
BARREL(A60, M1)	21304.00	0.000000
BARREL(A61, M1)	2338.000	0.000000
BARREL(A62, M1)	3784.000	0.000000
BARREL(A63, M1)	5642.000	0.000000
BARREL(A64, M1)	6510.000	0.000000
BARREL(A66, M1)	8009.000	0.000000
BARREL(A67, M1)	4972.000	0.000000
BARREL(A68, M1)	2771.000	0.000000
BARREL(A69, M1)	2324.000	0.000000
BARREL(A70, M1)	7448.000	0.000000
BARREL(A71, M1)	5438.000	0.000000
BARREL(A75, M1)	8195.000	0.000000
BARREL(A78, M1)	2417.000	0.000000
BARREL(A80, M1)	9259.000	0.000000
BARREL(A82, M1)	2552.000	0.000000
BARREL(A83, M1)	7115.000	0.000000

Row	Slack or Surplus	Dual Price
1	0.6509002E+09	-1.000000
2	0.000000	-4500.000
3	0.000000	4280.000
4	0.000000	4400.000
5	0.000000	1000.000
6	0.000000	4445.000
7	0.000000	2382.000
8	0.000000	1350.000
9	9896.000	0.000000
10	0.000000	4400.000
11	0.000000	1650.000
12	0.000000	2150.000
13	0.000000	400.0000

14	0.000000	4400.000
15	0.000000	100.0000
16	0.000000	4440.000
17	0.000000	2400.000
18	0.000000	2950.000
19	0.000000	2940.000
20	0.000000	3200.000
21	0.000000	3570.000
22	0.000000	2900.000
23	0.000000	3500.000
24	0.000000	1500.000
25	0.000000	3300.000
26	0.000000	2600.000
27	0.000000	4450.000
28	0.000000	4450.000
29	0.000000	3200.000
30	4374.000	0.000000
31	0.000000	1200.000
32	0.000000	1000.000
33	0.000000	2600.000
34	0.000000	800.0000
35	0.000000	3200.000
36	0.000000	2500.000
37	4228.000	0.000000
38	0.000000	2500.000
39	1421.000	0.000000
40	0.000000	1500.000
41	0.000000	500.0000
42	0.000000	2300.000
43	0.000000	1500.000
44	0.000000	3300.000
45	0.000000	4300.000
46	0.000000	800.0000
47	0.000000	3500.000
48	0.000000	500.0000
49	0.000000	3600.000
50	0.000000	4100.000
51	0.000000	1500.000
52	0.000000	500.0000
53	0.000000	500.0000

Figure 3 Lingo Out-put when Supply < Demand

```
No feasible solution found.
   Total solver iterations:                                    1


                         Variable           Value        Reduced Cost
                    CAPACITY( A1)        6719.000            0.000000
                    CAPACITY( A3)        24321.00            0.000000
                    CAPACITY( A4)        12546.00            0.000000
                    CAPACITY( A7)        6711.000            0.000000
                    CAPACITY( A8)        10606.00            0.000000
                   CAPACITY( A11)        782.0000            0.000000
                   CAPACITY( A13)        9896.000            0.000000
                   CAPACITY( A14)        2944.000            0.000000
                   CAPACITY( A15)        10951.00            0.000000
                   CAPACITY( A16)        6287.000            0.000000
                   CAPACITY( A17)        14606.00            0.000000
                   CAPACITY( A19)        9944.000            0.000000
                   CAPACITY( A20)        8411.000            0.000000
                   CAPACITY( A21)        8646.000            0.000000
                   CAPACITY( A22)        12263.00            0.000000
                   CAPACITY( A24)        4262.000            0.000000
                   CAPACITY( A25)        11475.00            0.000000
                   CAPACITY( A27)        4311.000            0.000000
                   CAPACITY( A28)        6422.000            0.000000
                   CAPACITY( A29)        7952.000            0.000000
                   CAPACITY( A30)        5072.000            0.000000
                   CAPACITY( A31)        6192.000            0.000000
                   CAPACITY( A38)        5020.000            0.000000
                   CAPACITY( A39)        2212.000            0.000000
                   CAPACITY( A41)        6938.000            0.000000
                   CAPACITY( A42)        4109.000            0.000000
                   CAPACITY( A46)        3722.000            0.000000
                   CAPACITY( A50)        4374.000            0.000000
                   CAPACITY( A52)        3223.000            0.000000
                   CAPACITY( A53)        5492.000            0.000000
                   CAPACITY( A54)        3180.000            0.000000
                   CAPACITY( A55)        7207.000            0.000000
                   CAPACITY( A56)        3700.000            0.000000
                   CAPACITY( A57)        3696.000            0.000000
                   CAPACITY( A58)        4228.000            0.000000
                   CAPACITY( A60)        21304.00            0.000000
                   CAPACITY( A61)        3759.000            0.000000
                   CAPACITY( A62)        3784.000            0.000000
                   CAPACITY( A63)        5642.000            0.000000
                   CAPACITY( A64)        6510.000            0.000000
                   CAPACITY( A66)        8009.000            0.000000
                   CAPACITY( A67)        4972.000            0.000000
                   CAPACITY( A68)        2771.000            0.000000
                   CAPACITY( A69)        2324.000            0.000000
                   CAPACITY( A70)        7448.000            0.000000
                   CAPACITY( A71)        5438.000            0.000000
                   CAPACITY( A75)        8195.000            0.000000
                   CAPACITY( A78)        2417.000            0.000000
                   CAPACITY( A80)        9259.000            0.000000
                   CAPACITY( A82)        2552.000            0.000000
```

Figure 3 Lingo Out-put when Supply < Demand

```
No feasible solution found.
   Total solver iterations:                          1
```

Variable	Value	Reduced Cost
CAPACITY(A1)	6719.000	0.000000
CAPACITY(A3)	24321.00	0.000000
CAPACITY(A4)	12546.00	0.000000
CAPACITY(A7)	6711.000	0.000000
CAPACITY(A8)	10606.00	0.000000
CAPACITY(A11)	782.0000	0.000000
CAPACITY(A13)	9896.000	0.000000
CAPACITY(A14)	2944.000	0.000000
CAPACITY(A15)	10951.00	0.000000
CAPACITY(A16)	6287.000	0.000000
CAPACITY(A17)	14606.00	0.000000
CAPACITY(A19)	9944.000	0.000000
CAPACITY(A20)	8411.000	0.000000
CAPACITY(A21)	8646.000	0.000000
CAPACITY(A22)	12263.00	0.000000
CAPACITY(A24)	4262.000	0.000000
CAPACITY(A25)	11475.00	0.000000
CAPACITY(A27)	4311.000	0.000000
CAPACITY(A28)	6422.000	0.000000
CAPACITY(A29)	7952.000	0.000000
CAPACITY(A30)	5072.000	0.000000
CAPACITY(A31)	6192.000	0.000000
CAPACITY(A38)	5020.000	0.000000
CAPACITY(A39)	2212.000	0.000000
CAPACITY(A41)	6938.000	0.000000
CAPACITY(A42)	4109.000	0.000000
CAPACITY(A46)	3722.000	0.000000
CAPACITY(A50)	4374.000	0.000000
CAPACITY(A52)	3223.000	0.000000
CAPACITY(A53)	5492.000	0.000000
CAPACITY(A54)	3180.000	0.000000
CAPACITY(A55)	7207.000	0.000000
CAPACITY(A56)	3700.000	0.000000
CAPACITY(A57)	3696.000	0.000000
CAPACITY(A58)	4228.000	0.000000
CAPACITY(A60)	21304.00	0.000000
CAPACITY(A61)	3759.000	0.000000
CAPACITY(A62)	3784.000	0.000000
CAPACITY(A63)	5642.000	0.000000
CAPACITY(A64)	6510.000	0.000000
CAPACITY(A66)	8009.000	0.000000
CAPACITY(A67)	4972.000	0.000000
CAPACITY(A68)	2771.000	0.000000
CAPACITY(A69)	2324.000	0.000000
CAPACITY(A70)	7448.000	0.000000
CAPACITY(A71)	5438.000	0.000000
CAPACITY(A75)	8195.000	0.000000
CAPACITY(A78)	2417.000	0.000000
CAPACITY(A80)	9259.000	0.000000
CAPACITY(A82)	2552.000	0.000000

CAPACITY(A83)	7115.000	0.000000
DEMAND(M1)	750000.0	0.000000
DISTANCE(A1, M1)	220.0000	0.000000
DISTANCE(A3, M1)	100.0000	0.000000
DISTANCE(A4, M1)	3500.000	0.000000
DISTANCE(A7, M1)	55.00000	0.000000
DISTANCE(A8, M1)	2118.000	0.000000
DISTANCE(A11, M1)	3150.000	0.000000
DISTANCE(A13, M1)	6300.000	0.000000
DISTANCE(A14, M1)	100.0000	0.000000
DISTANCE(A15, M1)	2850.000	0.000000
DISTANCE(A16, M1)	2350.000	0.000000
DISTANCE(A17, M1)	4100.000	0.000000
DISTANCE(A19, M1)	100.0000	0.000000
DISTANCE(A20, M1)	4400.000	0.000000
DISTANCE(A21, M1)	60.00000	0.000000
DISTANCE(A22, M1)	2100.000	0.000000
DISTANCE(A24, M1)	1550.000	0.000000
DISTANCE(A25, M1)	1560.000	0.000000
DISTANCE(A27, M1)	1300.000	0.000000
DISTANCE(A28, M1)	930.0000	0.000000
DISTANCE(A29, M1)	1600.000	0.000000
DISTANCE(A30, M1)	1000.000	0.000000
DISTANCE(A31, M1)	3000.000	0.000000
DISTANCE(A38, M1)	1200.000	0.000000
DISTANCE(A39, M1)	1900.000	0.000000
DISTANCE(A41, M1)	50.00000	0.000000
DISTANCE(A42, M1)	50.00000	0.000000
DISTANCE(A46, M1)	1300.000	0.000000
DISTANCE(A50, M1)	4500.000	0.000000
DISTANCE(A52, M1)	3300.000	0.000000
DISTANCE(A53, M1)	3500.000	0.000000
DISTANCE(A54, M1)	1900.000	0.000000
DISTANCE(A55, M1)	3700.000	0.000000
DISTANCE(A56, M1)	1300.000	0.000000
DISTANCE(A57, M1)	2000.000	0.000000
DISTANCE(A58, M1)	5900.000	0.000000
DISTANCE(A60, M1)	2000.000	0.000000
DISTANCE(A61, M1)	4500.000	0.000000
DISTANCE(A62, M1)	3000.000	0.000000
DISTANCE(A63, M1)	4000.000	0.000000
DISTANCE(A64, M1)	2200.000	0.000000
DISTANCE(A66, M1)	3000.000	0.000000
DISTANCE(A67, M1)	1200.000	0.000000
DISTANCE(A68, M1)	200.0000	0.000000
DISTANCE(A69, M1)	3700.000	0.000000
DISTANCE(A70, M1)	1000.000	0.000000
DISTANCE(A71, M1)	4000.000	0.000000
DISTANCE(A75, M1)	900.0000	0.000000
DISTANCE(A78, M1)	400.0000	0.000000
DISTANCE(A80, M1)	3000.000	0.000000
DISTANCE(A82, M1)	4000.000	0.000000
DISTANCE(A83, M1)	4000.000	0.000000
BARREL(A1, M1)	6719.000	0.000000
BARREL(A3, M1)	24321.00	0.000000
BARREL(A4, M1)	12546.00	0.000000
BARREL(A7, M1)	6711.000	0.000000
BARREL(A8, M1)	10606.00	0.000000
BARREL(A11, M1)	782.0000	0.000000
BARREL(A13, M1)	409977.0	0.000000
BARREL(A14, M1)	2944.000	0.000000

BARREL(A15, M1)	10951.00	0.000000
BARREL(A16, M1)	6287.000	0.000000
BARREL(A17, M1)	14606.00	0.000000
BARREL(A19, M1)	9944.000	0.000000
BARREL(A20, M1)	8411.000	0.000000
BARREL(A21, M1)	8646.000	0.000000
BARREL(A22, M1)	12263.00	0.000000
BARREL(A24, M1)	4262.000	0.000000
BARREL(A25, M1)	11475.00	0.000000
BARREL(A27, M1)	4311.000	0.000000
BARREL(A28, M1)	6422.000	0.000000
BARREL(A29, M1)	7952.000	0.000000
BARREL(A30, M1)	5072.000	0.000000
BARREL(A31, M1)	6192.000	0.000000
BARREL(A38, M1)	5020.000	0.000000
BARREL(A39, M1)	2212.000	0.000000
BARREL(A41, M1)	6938.000	0.000000
BARREL(A42, M1)	4109.000	0.000000
BARREL(A46, M1)	3722.000	0.000000
BARREL(A50, M1)	4374.000	0.000000
BARREL(A52, M1)	3223.000	0.000000
BARREL(A53, M1)	5492.000	0.000000
BARREL(A54, M1)	3180.000	0.000000
BARREL(A55, M1)	7207.000	0.000000
BARREL(A56, M1)	3700.000	0.000000
BARREL(A57, M1)	3696.000	0.000000
BARREL(A58, M1)	4228.000	0.000000
BARREL(A60, M1)	21304.00	0.000000
BARREL(A61, M1)	3759.000	0.000000
BARREL(A62, M1)	3784.000	0.000000
BARREL(A63, M1)	5642.000	0.000000
BARREL(A64, M1)	6510.000	0.000000
BARREL(A66, M1)	8009.000	0.000000
BARREL(A67, M1)	4972.000	0.000000
BARREL(A68, M1)	2771.000	0.000000
BARREL(A69, M1)	2324.000	0.000000
BARREL(A70, M1)	7448.000	0.000000
BARREL(A71, M1)	5438.000	0.000000
BARREL(A75, M1)	8195.000	0.000000
BARREL(A78, M1)	2417.000	0.000000
BARREL(A80, M1)	9259.000	0.000000
BARREL(A82, M1)	2552.000	0.000000
BARREL(A83, M1)	7115.000	0.000000

Row	Slack or Surplus	Dual Price
1	400081.0	-1.000000
2	0.000000	-6300.000
3	0.000000	6080.000
4	0.000000	6200.000
5	0.000000	2800.000
6	0.000000	6245.000
7	0.000000	4182.000
8	0.000000	3150.000
9	-400081.0	0.000000
10	0.000000	6200.000
11	0.000000	3450.000
12	0.000000	3950.000
13	0.000000	2200.000
14	0.000000	6200.000
15	0.000000	1900.000
16	0.000000	6240.000

17	0.000000	4200.000
18	0.000000	4750.000
19	0.000000	4740.000
20	0.000000	5000.000
21	0.000000	5370.000
22	0.000000	4700.000
23	0.000000	5300.000
24	0.000000	3300.000
25	0.000000	5100.000
26	0.000000	4400.000
27	0.000000	6250.000
28	0.000000	6250.000
29	0.000000	5000.000
30	0.000000	1800.000
31	0.000000	3000.000
32	0.000000	2800.000
33	0.000000	4400.000
34	0.000000	2600.000
35	0.000000	5000.000
36	0.000000	4300.000
37	0.000000	400.0000
38	0.000000	4300.000
39	0.000000	1800.000
40	0.000000	3300.000
41	0.000000	2300.000
42	0.000000	4100.000
43	0.000000	3300.000
44	0.000000	5100.000
45	0.000000	6100.000
46	0.000000	2600.000
47	0.000000	5300.000
48	0.000000	2300.000
49	0.000000	5400.000
50	0.000000	5900.000
51	0.000000	3300.000
52	0.000000	2300.000
53	0.000000	2300.000

Figure 4 Lingo Out-put when Demand > Supply (Dummy Solution)

```
Global optimal solution found.
   Objective value:                              0.7642677E+09
   Total solver iterations:                                  0
```

Variable	Value	Reduced Cost
CAPACITY(A1)	6719.000	0.000000
CAPACITY(A3)	24321.00	0.000000
CAPACITY(A4)	12546.00	0.000000
CAPACITY(A7)	6711.000	0.000000
CAPACITY(A8)	10606.00	0.000000
CAPACITY(A11)	782.0000	0.000000
CAPACITY(A13)	9896.000	0.000000
CAPACITY(A14)	2944.000	0.000000
CAPACITY(A15)	10951.00	0.000000
CAPACITY(A16)	6287.000	0.000000
CAPACITY(A17)	14606.00	0.000000
CAPACITY(A19)	9944.000	0.000000
CAPACITY(A20)	8411.000	0.000000
CAPACITY(A21)	8646.000	0.000000
CAPACITY(A22)	12263.00	0.000000
CAPACITY(A24)	4262.000	0.000000
CAPACITY(A25)	11475.00	0.000000
CAPACITY(A27)	4311.000	0.000000
CAPACITY(A28)	6422.000	0.000000
CAPACITY(A29)	7952.000	0.000000
CAPACITY(A30)	5072.000	0.000000
CAPACITY(A31)	6192.000	0.000000
CAPACITY(A38)	5020.000	0.000000
CAPACITY(A39)	2212.000	0.000000
CAPACITY(A41)	6938.000	0.000000
CAPACITY(A42)	4109.000	0.000000
CAPACITY(A46)	3722.000	0.000000
CAPACITY(A50)	4374.000	0.000000
CAPACITY(A52)	3223.000	0.000000
CAPACITY(A53)	5492.000	0.000000
CAPACITY(A54)	3180.000	0.000000
CAPACITY(A55)	7207.000	0.000000
CAPACITY(A56)	3700.000	0.000000
CAPACITY(A57)	3696.000	0.000000
CAPACITY(A58)	4228.000	0.000000
CAPACITY(A60)	21304.00	0.000000
CAPACITY(A61)	3759.000	0.000000
CAPACITY(A62)	3784.000	0.000000
CAPACITY(A63)	5642.000	0.000000
CAPACITY(A64)	6510.000	0.000000
CAPACITY(A66)	8009.000	0.000000
CAPACITY(A67)	4972.000	0.000000
CAPACITY(A68)	2771.000	0.000000
CAPACITY(A69)	2324.000	0.000000
CAPACITY(A70)	7448.000	0.000000
CAPACITY(A71)	5438.000	0.000000
CAPACITY(A75)	8195.000	0.000000
CAPACITY(A78)	2417.000	0.000000
CAPACITY(A80)	9259.000	0.000000

CAPACITY(A82)	2552.000	0.000000
CAPACITY(A83)	7115.000	0.000000
CAPACITY(A84)	10081.00	0.000000
DEMAND(M1)	360000.0	0.000000
DISTANCE(A1, M1)	220.0000	0.000000
DISTANCE(A3, M1)	100.0000	0.000000
DISTANCE(A4, M1)	3500.000	0.000000
DISTANCE(A7, M1)	55.00000	0.000000
DISTANCE(A8, M1)	2118.000	0.000000
DISTANCE(A11, M1)	3150.000	0.000000
DISTANCE(A13, M1)	6300.000	0.000000
DISTANCE(A14, M1)	100.0000	0.000000
DISTANCE(A15, M1)	2850.000	0.000000
DISTANCE(A16, M1)	2350.000	0.000000
DISTANCE(A17, M1)	4100.000	0.000000
DISTANCE(A19, M1)	100.0000	0.000000
DISTANCE(A20, M1)	4400.000	0.000000
DISTANCE(A21, M1)	60.00000	0.000000
DISTANCE(A22, M1)	2100.000	0.000000
DISTANCE(A24, M1)	1550.000	0.000000
DISTANCE(A25, M1)	1560.000	0.000000
DISTANCE(A27, M1)	1300.000	0.000000
DISTANCE(A28, M1)	930.0000	0.000000
DISTANCE(A29, M1)	1600.000	0.000000
DISTANCE(A30, M1)	1000.000	0.000000
DISTANCE(A31, M1)	3000.000	0.000000
DISTANCE(A38, M1)	1200.000	0.000000
DISTANCE(A39, M1)	1900.000	0.000000
DISTANCE(A41, M1)	50.00000	0.000000
DISTANCE(A42, M1)	50.00000	0.000000
DISTANCE(A46, M1)	1300.000	0.000000
DISTANCE(A50, M1)	4500.000	0.000000
DISTANCE(A52, M1)	3300.000	0.000000
DISTANCE(A53, M1)	3500.000	0.000000
DISTANCE(A54, M1)	1900.000	0.000000
DISTANCE(A55, M1)	3700.000	0.000000
DISTANCE(A56, M1)	1300.000	0.000000
DISTANCE(A57, M1)	2000.000	0.000000
DISTANCE(A58, M1)	5900.000	0.000000
DISTANCE(A60, M1)	2000.000	0.000000
DISTANCE(A61, M1)	4500.000	0.000000
DISTANCE(A62, M1)	3000.000	0.000000
DISTANCE(A63, M1)	4000.000	0.000000
DISTANCE(A64, M1)	2200.000	0.000000
DISTANCE(A66, M1)	3000.000	0.000000
DISTANCE(A67, M1)	1200.000	0.000000
DISTANCE(A68, M1)	200.0000	0.000000
DISTANCE(A69, M1)	3700.000	0.000000
DISTANCE(A70, M1)	1000.000	0.000000
DISTANCE(A71, M1)	4000.000	0.000000
DISTANCE(A75, M1)	900.0000	0.000000
DISTANCE(A78, M1)	400.0000	0.000000
DISTANCE(A80, M1)	3000.000	0.000000
DISTANCE(A82, M1)	4000.000	0.000000
DISTANCE(A83, M1)	4000.000	0.000000
DISTANCE(A84, M1)	0.000000	0.000000
BARREL(A1, M1)	6719.000	0.000000
BARREL(A3, M1)	24321.00	0.000000
BARREL(A4, M1)	12546.00	0.000000
BARREL(A7, M1)	6711.000	0.000000
BARREL(A8, M1)	10606.00	0.000000

BARREL(A11, M1)	782.0000	0.000000
BARREL(A13, M1)	9896.000	0.000000
BARREL(A14, M1)	2944.000	0.000000
BARREL(A15, M1)	10951.00	0.000000
BARREL(A16, M1)	6287.000	0.000000
BARREL(A17, M1)	14606.00	0.000000
BARREL(A19, M1)	9944.000	0.000000
BARREL(A20, M1)	8411.000	0.000000
BARREL(A21, M1)	8646.000	0.000000
BARREL(A22, M1)	12263.00	0.000000
BARREL(A24, M1)	4262.000	0.000000
BARREL(A25, M1)	11475.00	0.000000
BARREL(A27, M1)	4311.000	0.000000
BARREL(A28, M1)	6422.000	0.000000
BARREL(A29, M1)	7952.000	0.000000
BARREL(A30, M1)	5072.000	0.000000
BARREL(A31, M1)	6192.000	0.000000
BARREL(A38, M1)	5020.000	0.000000
BARREL(A39, M1)	2212.000	0.000000
BARREL(A41, M1)	6938.000	0.000000
BARREL(A42, M1)	4109.000	0.000000
BARREL(A46, M1)	3722.000	0.000000
BARREL(A50, M1)	4374.000	0.000000
BARREL(A52, M1)	3223.000	0.000000
BARREL(A53, M1)	5492.000	0.000000
BARREL(A54, M1)	3180.000	0.000000
BARREL(A55, M1)	7207.000	0.000000
BARREL(A56, M1)	3700.000	0.000000
BARREL(A57, M1)	3696.000	0.000000
BARREL(A58, M1)	4228.000	0.000000
BARREL(A60, M1)	21304.00	0.000000
BARREL(A61, M1)	3759.000	0.000000
BARREL(A62, M1)	3784.000	0.000000
BARREL(A63, M1)	5642.000	0.000000
BARREL(A64, M1)	6510.000	0.000000
BARREL(A66, M1)	8009.000	0.000000
BARREL(A67, M1)	4972.000	0.000000
BARREL(A68, M1)	2771.000	0.000000
BARREL(A69, M1)	2324.000	0.000000
BARREL(A70, M1)	7448.000	0.000000
BARREL(A71, M1)	5438.000	0.000000
BARREL(A75, M1)	8195.000	0.000000
BARREL(A78, M1)	2417.000	0.000000
BARREL(A80, M1)	9259.000	0.000000
BARREL(A82, M1)	2552.000	0.000000
BARREL(A83, M1)	7115.000	0.000000
BARREL(A84, M1)	10081.00	0.000000

Row	Slack or Surplus	Dual Price
1	0.7642677E+09	-1.000000
2	0.000000	-6300.000
3	0.000000	6080.000
4	0.000000	6200.000
5	0.000000	2800.000
6	0.000000	6245.000
7	0.000000	4182.000
8	0.000000	3150.000
9	0.000000	0.000000
10	0.000000	6200.000
11	0.000000	3450.000
12	0.000000	3950.000

13	0.000000	2200.000
14	0.000000	6200.000
15	0.000000	1900.000
16	0.000000	6240.000
17	0.000000	4200.000
18	0.000000	4750.000
19	0.000000	4740.000
20	0.000000	5000.000
21	0.000000	5370.000
22	0.000000	4700.000
23	0.000000	5300.000
24	0.000000	3300.000
25	0.000000	5100.000
26	0.000000	4400.000
27	0.000000	6250.000
28	0.000000	6250.000
29	0.000000	5000.000
30	0.000000	1800.000
31	0.000000	3000.000
32	0.000000	2800.000
33	0.000000	4400.000
34	0.000000	2600.000
35	0.000000	5000.000
36	0.000000	4300.000
37	0.000000	400.0000
38	0.000000	4300.000
39	0.000000	1800.000
40	0.000000	3300.000
41	0.000000	2300.000
42	0.000000	4100.000
43	0.000000	3300.000
44	0.000000	5100.000
45	0.000000	6100.000
46	0.000000	2600.000
47	0.000000	5300.000
48	0.000000	2300.000
49	0.000000	5400.000
50	0.000000	5900.000
51	0.000000	3300.000
52	0.000000	2300.000
53	0.000000	2300.000
54	0.000000	6300.000

Figure 5 Lingo Out-put when Supply > Demand (Dummy Solution)

```
Global optimal solution found.
   Objective value:                              0.7017872E+09
   Total solver iterations:                             61


                       Variable           Value        Reduced Cost
                  CAPACITY( A1)        6719.000            0.000000
                  CAPACITY( A3)        24321.00            0.000000
                  CAPACITY( A4)        12546.00            0.000000
                  CAPACITY( A7)        6711.000            0.000000
                  CAPACITY( A8)        10606.00            0.000000
                 CAPACITY( A11)        782.0000            0.000000
                 CAPACITY( A13)        9896.000            0.000000
                 CAPACITY( A14)        2944.000            0.000000
                 CAPACITY( A15)        10951.00            0.000000
                 CAPACITY( A16)        6287.000            0.000000
                 CAPACITY( A17)        14606.00            0.000000
                 CAPACITY( A19)        9944.000            0.000000
                 CAPACITY( A20)        8411.000            0.000000
                 CAPACITY( A21)        8646.000            0.000000
                 CAPACITY( A22)        12263.00            0.000000
                 CAPACITY( A24)        4262.000            0.000000
                 CAPACITY( A25)        11475.00            0.000000
                 CAPACITY( A27)        4311.000            0.000000
                 CAPACITY( A28)        6422.000            0.000000
                 CAPACITY( A29)        7952.000            0.000000
                 CAPACITY( A30)        5072.000            0.000000
                 CAPACITY( A31)        6192.000            0.000000
                 CAPACITY( A38)        5020.000            0.000000
                 CAPACITY( A39)        2212.000            0.000000
                 CAPACITY( A41)        6938.000            0.000000
                 CAPACITY( A42)        4109.000            0.000000
                 CAPACITY( A46)        3722.000            0.000000
                 CAPACITY( A50)        4374.000            0.000000
                 CAPACITY( A52)        3223.000            0.000000
                 CAPACITY( A53)        5492.000            0.000000
                 CAPACITY( A54)        3180.000            0.000000
                 CAPACITY( A55)        7207.000            0.000000
                 CAPACITY( A56)        3700.000            0.000000
                 CAPACITY( A57)        3696.000            0.000000
                 CAPACITY( A58)        4228.000            0.000000
                 CAPACITY( A60)        21304.00            0.000000
                 CAPACITY( A61)        3759.000            0.000000
                 CAPACITY( A62)        3784.000            0.000000
                 CAPACITY( A63)        5642.000            0.000000
                 CAPACITY( A64)        6510.000            0.000000
                 CAPACITY( A66)        8009.000            0.000000
                 CAPACITY( A67)        4972.000            0.000000
                 CAPACITY( A68)        2771.000            0.000000
                 CAPACITY( A69)        2324.000            0.000000
                 CAPACITY( A70)        7448.000            0.000000
                 CAPACITY( A71)        5438.000            0.000000
                 CAPACITY( A75)        8195.000            0.000000
                 CAPACITY( A78)        2417.000            0.000000
                 CAPACITY( A80)        9259.000            0.000000
```

CAPACITY(A82)	2552.000	0.000000
CAPACITY(A83)	7115.000	0.000000
DEMAND(M1)	340000.0	0.000000
DEMAND(M2)	9919.000	0.000000
DISTANCE(A1, M1)	220.0000	0.000000
DISTANCE(A1, M2)	0.000000	0.000000
DISTANCE(A3, M1)	100.0000	0.000000
DISTANCE(A3, M2)	0.000000	0.000000
DISTANCE(A4, M1)	3500.000	0.000000
DISTANCE(A4, M2)	0.000000	0.000000
DISTANCE(A7, M1)	55.00000	0.000000
DISTANCE(A7, M2)	0.000000	0.000000
DISTANCE(A8, M1)	2118.000	0.000000
DISTANCE(A8, M2)	0.000000	0.000000
DISTANCE(A11, M1)	3150.000	0.000000
DISTANCE(A11, M2)	0.000000	0.000000
DISTANCE(A13, M1)	6300.000	0.000000
DISTANCE(A13, M2)	0.000000	0.000000
DISTANCE(A14, M1)	100.0000	0.000000
DISTANCE(A14, M2)	0.000000	0.000000
DISTANCE(A15, M1)	2850.000	0.000000
DISTANCE(A15, M2)	0.000000	0.000000
DISTANCE(A16, M1)	2350.000	0.000000
DISTANCE(A16, M2)	0.000000	0.000000
DISTANCE(A17, M1)	4100.000	0.000000
DISTANCE(A17, M2)	0.000000	0.000000
DISTANCE(A19, M1)	100.0000	0.000000
DISTANCE(A19, M2)	0.000000	0.000000
DISTANCE(A20, M1)	4400.000	0.000000
DISTANCE(A20, M2)	0.000000	0.000000
DISTANCE(A21, M1)	60.00000	0.000000
DISTANCE(A21, M2)	0.000000	0.000000
DISTANCE(A22, M1)	2100.000	0.000000
DISTANCE(A22, M2)	0.000000	0.000000
DISTANCE(A24, M1)	1550.000	0.000000
DISTANCE(A24, M2)	0.000000	0.000000
DISTANCE(A25, M1)	1560.000	0.000000
DISTANCE(A25, M2)	0.000000	0.000000
DISTANCE(A27, M1)	1300.000	0.000000
DISTANCE(A27, M2)	0.000000	0.000000
DISTANCE(A28, M1)	930.0000	0.000000
DISTANCE(A28, M2)	0.000000	0.000000
DISTANCE(A29, M1)	1600.000	0.000000
DISTANCE(A29, M2)	0.000000	0.000000
DISTANCE(A30, M1)	1000.000	0.000000
DISTANCE(A30, M2)	0.000000	0.000000
DISTANCE(A31, M1)	3000.000	0.000000
DISTANCE(A31, M2)	0.000000	0.000000
DISTANCE(A38, M1)	1200.000	0.000000
DISTANCE(A38, M2)	0.000000	0.000000
DISTANCE(A39, M1)	1900.000	0.000000
DISTANCE(A39, M2)	0.000000	0.000000
DISTANCE(A41, M1)	50.00000	0.000000
DISTANCE(A41, M2)	0.000000	0.000000
DISTANCE(A42, M1)	50.00000	0.000000
DISTANCE(A42, M2)	0.000000	0.000000
DISTANCE(A46, M1)	1300.000	0.000000
DISTANCE(A46, M2)	0.000000	0.000000
DISTANCE(A50, M1)	4500.000	0.000000
DISTANCE(A50, M2)	0.000000	0.000000
DISTANCE(A52, M1)	3300.000	0.000000

DISTANCE(A52, M2)	0.000000	0.000000
DISTANCE(A53, M1)	3500.000	0.000000
DISTANCE(A53, M2)	0.000000	0.000000
DISTANCE(A54, M1)	1900.000	0.000000
DISTANCE(A54, M2)	0.000000	0.000000
DISTANCE(A55, M1)	3700.000	0.000000
DISTANCE(A55, M2)	0.000000	0.000000
DISTANCE(A56, M1)	1300.000	0.000000
DISTANCE(A56, M2)	0.000000	0.000000
DISTANCE(A57, M1)	2000.000	0.000000
DISTANCE(A57, M2)	0.000000	0.000000
DISTANCE(A58, M1)	5900.000	0.000000
DISTANCE(A58, M2)	0.000000	0.000000
DISTANCE(A60, M1)	2000.000	0.000000
DISTANCE(A60, M2)	0.000000	0.000000
DISTANCE(A61, M1)	4500.000	0.000000
DISTANCE(A61, M2)	0.000000	0.000000
DISTANCE(A62, M1)	3000.000	0.000000
DISTANCE(A62, M2)	0.000000	0.000000
DISTANCE(A63, M1)	4000.000	0.000000
DISTANCE(A63, M2)	0.000000	0.000000
DISTANCE(A64, M1)	2200.000	0.000000
DISTANCE(A64, M2)	0.000000	0.000000
DISTANCE(A66, M1)	3000.000	0.000000
DISTANCE(A66, M2)	0.000000	0.000000
DISTANCE(A67, M1)	1200.000	0.000000
DISTANCE(A67, M2)	0.000000	0.000000
DISTANCE(A68, M1)	200.0000	0.000000
DISTANCE(A68, M2)	0.000000	0.000000
DISTANCE(A69, M1)	3700.000	0.000000
DISTANCE(A69, M2)	0.000000	0.000000
DISTANCE(A70, M1)	1000.000	0.000000
DISTANCE(A70, M2)	0.000000	0.000000
DISTANCE(A71, M1)	4000.000	0.000000
DISTANCE(A71, M2)	0.000000	0.000000
DISTANCE(A75, M1)	900.0000	0.000000
DISTANCE(A75, M2)	0.000000	0.000000
DISTANCE(A78, M1)	400.0000	0.000000
DISTANCE(A78, M2)	0.000000	0.000000
DISTANCE(A80, M1)	3000.000	0.000000
DISTANCE(A80, M2)	0.000000	0.000000
DISTANCE(A82, M1)	4000.000	0.000000
DISTANCE(A82, M2)	0.000000	0.000000
DISTANCE(A83, M1)	4000.000	0.000000
DISTANCE(A83, M2)	0.000000	0.000000
BARREL(A1, M1)	6719.000	0.000000
BARREL(A1, M2)	0.000000	5680.000
BARREL(A3, M1)	24321.00	0.000000
BARREL(A3, M2)	0.000000	5800.000
BARREL(A4, M1)	12546.00	0.000000
BARREL(A4, M2)	0.000000	2400.000
BARREL(A7, M1)	6711.000	0.000000
BARREL(A7, M2)	0.000000	5845.000
BARREL(A8, M1)	10606.00	0.000000
BARREL(A8, M2)	0.000000	3782.000
BARREL(A11, M1)	782.0000	0.000000
BARREL(A11, M2)	0.000000	2750.000
BARREL(A13, M1)	0.000000	400.0000
BARREL(A13, M2)	9896.000	0.000000
BARREL(A14, M1)	2944.000	0.000000
BARREL(A14, M2)	0.000000	5800.000

BARREL(A15, M1)	10951.00	0.000000
BARREL(A15, M2)	0.000000	3050.000
BARREL(A16, M1)	6287.000	0.000000
BARREL(A16, M2)	0.000000	3550.000
BARREL(A17, M1)	14606.00	0.000000
BARREL(A17, M2)	0.000000	1800.000
BARREL(A19, M1)	9944.000	0.000000
BARREL(A19, M2)	0.000000	5800.000
BARREL(A20, M1)	8411.000	0.000000
BARREL(A20, M2)	0.000000	1500.000
BARREL(A21, M1)	8646.000	0.000000
BARREL(A21, M2)	0.000000	5840.000
BARREL(A22, M1)	12263.00	0.000000
BARREL(A22, M2)	0.000000	3800.000
BARREL(A24, M1)	4262.000	0.000000
BARREL(A24, M2)	0.000000	4350.000
BARREL(A25, M1)	11475.00	0.000000
BARREL(A25, M2)	0.000000	4340.000
BARREL(A27, M1)	4311.000	0.000000
BARREL(A27, M2)	0.000000	4600.000
BARREL(A28, M1)	6422.000	0.000000
BARREL(A28, M2)	0.000000	4970.000
BARREL(A29, M1)	7952.000	0.000000
BARREL(A29, M2)	0.000000	4300.000
BARREL(A30, M1)	5072.000	0.000000
BARREL(A30, M2)	0.000000	4900.000
BARREL(A31, M1)	6192.000	0.000000
BARREL(A31, M2)	0.000000	2900.000
BARREL(A38, M1)	5020.000	0.000000
BARREL(A38, M2)	0.000000	4700.000
BARREL(A39, M1)	2212.000	0.000000
BARREL(A39, M2)	0.000000	4000.000
BARREL(A41, M1)	6938.000	0.000000
BARREL(A41, M2)	0.000000	5850.000
BARREL(A42, M1)	4109.000	0.000000
BARREL(A42, M2)	0.000000	5850.000
BARREL(A46, M1)	3722.000	0.000000
BARREL(A46, M2)	0.000000	4600.000
BARREL(A50, M1)	4374.000	0.000000
BARREL(A50, M2)	0.000000	1400.000
BARREL(A52, M1)	3223.000	0.000000
BARREL(A52, M2)	0.000000	2600.000
BARREL(A53, M1)	5492.000	0.000000
BARREL(A53, M2)	0.000000	2400.000
BARREL(A54, M1)	3180.000	0.000000
BARREL(A54, M2)	0.000000	4000.000
BARREL(A55, M1)	7207.000	0.000000
BARREL(A55, M2)	0.000000	2200.000
BARREL(A56, M1)	3700.000	0.000000
BARREL(A56, M2)	0.000000	4600.000
BARREL(A57, M1)	3696.000	0.000000
BARREL(A57, M2)	0.000000	3900.000
BARREL(A58, M1)	4205.000	0.000000
BARREL(A58, M2)	23.00000	0.000000
BARREL(A60, M1)	21304.00	0.000000
BARREL(A60, M2)	0.000000	3900.000
BARREL(A61, M1)	3759.000	0.000000
BARREL(A61, M2)	0.000000	1400.000
BARREL(A62, M1)	3784.000	0.000000
BARREL(A62, M2)	0.000000	2900.000
BARREL(A63, M1)	5642.000	0.000000

BARREL(A63, M2)	0.000000	1900.000
BARREL(A64, M1)	6510.000	0.000000
BARREL(A64, M2)	0.000000	3700.000
BARREL(A66, M1)	8009.000	0.000000
BARREL(A66, M2)	0.000000	2900.000
BARREL(A67, M1)	4972.000	0.000000
BARREL(A67, M2)	0.000000	4700.000
BARREL(A68, M1)	2771.000	0.000000
BARREL(A68, M2)	0.000000	5700.000
BARREL(A69, M1)	2324.000	0.000000
BARREL(A69, M2)	0.000000	2200.000
BARREL(A70, M1)	7448.000	0.000000
BARREL(A70, M2)	0.000000	4900.000
BARREL(A71, M1)	5438.000	0.000000
BARREL(A71, M2)	0.000000	1900.000
BARREL(A75, M1)	8195.000	0.000000
BARREL(A75, M2)	0.000000	5000.000
BARREL(A78, M1)	2417.000	0.000000
BARREL(A78, M2)	0.000000	5500.000
BARREL(A80, M1)	9259.000	0.000000
BARREL(A80, M2)	0.000000	2900.000
BARREL(A82, M1)	2552.000	0.000000
BARREL(A82, M2)	0.000000	1900.000
BARREL(A83, M1)	7115.000	0.000000
BARREL(A83, M2)	0.000000	1900.000

Row	Slack or Surplus	Dual Price
1	0.7017872E+09	-1.000000
2	0.000000	-5900.000
3	0.000000	0.000000
4	0.000000	5680.000
5	0.000000	5800.000
6	0.000000	2400.000
7	0.000000	5845.000
8	0.000000	3782.000
9	0.000000	2750.000
10	0.000000	0.000000
11	0.000000	5800.000
12	0.000000	3050.000
13	0.000000	3550.000
14	0.000000	1800.000
15	0.000000	5800.000
16	0.000000	1500.000
17	0.000000	5840.000
18	0.000000	3800.000
19	0.000000	4350.000
20	0.000000	4340.000
21	0.000000	4600.000
22	0.000000	4970.000
23	0.000000	4300.000
24	0.000000	4900.000
25	0.000000	2900.000
26	0.000000	4700.000
27	0.000000	4000.000
28	0.000000	5850.000
29	0.000000	5850.000
30	0.000000	4600.000
31	0.000000	1400.000
32	0.000000	2600.000
33	0.000000	2400.000
34	0.000000	4000.000

35	0.000000	2200.000
36	0.000000	4600.000
37	0.000000	3900.000
38	0.000000	0.000000
39	0.000000	3900.000
40	0.000000	1400.000
41	0.000000	2900.000
42	0.000000	1900.000
43	0.000000	3700.000
44	0.000000	2900.000
45	0.000000	4700.000
46	0.000000	5700.000
47	0.000000	2200.000
48	0.000000	4900.000
49	0.000000	1900.000
50	0.000000	5000.000
51	0.000000	5500.000
52	0.000000	2900.000
53	0.000000	1900.000
54	0.000000	1900.000

Figure 6 Supply > Demand (Dummy Solution)

```
Global optimal solution found.
   Objective value:                              0.7017872E+09
   Total solver iterations:                                 61
```

Variable	Value	Reduced Cost
CAPACITY(A1)	6719.000	0.000000
CAPACITY(A3)	24321.00	0.000000
CAPACITY(A4)	12546.00	0.000000
CAPACITY(A7)	6711.000	0.000000
CAPACITY(A8)	10606.00	0.000000
CAPACITY(A11)	782.0000	0.000000
CAPACITY(A13)	9896.000	0.000000
CAPACITY(A14)	2944.000	0.000000
CAPACITY(A15)	10951.00	0.000000
CAPACITY(A16)	6287.000	0.000000
CAPACITY(A17)	14606.00	0.000000
CAPACITY(A19)	9944.000	0.000000
CAPACITY(A20)	8411.000	0.000000
CAPACITY(A21)	8646.000	0.000000
CAPACITY(A22)	12263.00	0.000000
CAPACITY(A24)	4262.000	0.000000
CAPACITY(A25)	11475.00	0.000000
CAPACITY(A27)	4311.000	0.000000
CAPACITY(A28)	6422.000	0.000000
CAPACITY(A29)	7952.000	0.000000
CAPACITY(A30)	5072.000	0.000000
CAPACITY(A31)	6192.000	0.000000
CAPACITY(A38)	5020.000	0.000000
CAPACITY(A39)	2212.000	0.000000
CAPACITY(A41)	6938.000	0.000000
CAPACITY(A42)	4109.000	0.000000
CAPACITY(A46)	3722.000	0.000000
CAPACITY(A50)	4374.000	0.000000
CAPACITY(A52)	3223.000	0.000000
CAPACITY(A53)	5492.000	0.000000
CAPACITY(A54)	3180.000	0.000000
CAPACITY(A55)	7207.000	0.000000
CAPACITY(A56)	3700.000	0.000000
CAPACITY(A57)	3696.000	0.000000
CAPACITY(A58)	4228.000	0.000000
CAPACITY(A60)	21304.00	0.000000
CAPACITY(A61)	3759.000	0.000000
CAPACITY(A62)	3784.000	0.000000
CAPACITY(A63)	5642.000	0.000000
CAPACITY(A64)	6510.000	0.000000
CAPACITY(A66)	8009.000	0.000000
CAPACITY(A67)	4972.000	0.000000
CAPACITY(A68)	2771.000	0.000000
CAPACITY(A69)	2324.000	0.000000
CAPACITY(A70)	7448.000	0.000000
CAPACITY(A71)	5438.000	0.000000
CAPACITY(A75)	8195.000	0.000000
CAPACITY(A78)	2417.000	0.000000
CAPACITY(A80)	9259.000	0.000000
CAPACITY(A82)	2552.000	0.000000
CAPACITY(A83)	7115.000	0.000000

DEMAND(M1)	340000.0	0.000000
DEMAND(M2)	9919.000	0.000000
DISTANCE(A1, M1)	220.0000	0.000000
DISTANCE(A1, M2)	0.000000	0.000000
DISTANCE(A3, M1)	100.0000	0.000000
DISTANCE(A3, M2)	0.000000	0.000000
DISTANCE(A4, M1)	3500.000	0.000000
DISTANCE(A4, M2)	0.000000	0.000000
DISTANCE(A7, M1)	55.00000	0.000000
DISTANCE(A7, M2)	0.000000	0.000000
DISTANCE(A8, M1)	2118.000	0.000000
DISTANCE(A8, M2)	0.000000	0.000000
DISTANCE(A11, M1)	3150.000	0.000000
DISTANCE(A11, M2)	0.000000	0.000000
DISTANCE(A13, M1)	6300.000	0.000000
DISTANCE(A13, M2)	0.000000	0.000000
DISTANCE(A14, M1)	100.0000	0.000000
DISTANCE(A14, M2)	0.000000	0.000000
DISTANCE(A15, M1)	2850.000	0.000000
DISTANCE(A15, M2)	0.000000	0.000000
DISTANCE(A16, M1)	2350.000	0.000000
DISTANCE(A16, M2)	0.000000	0.000000
DISTANCE(A17, M1)	4100.000	0.000000
DISTANCE(A17, M2)	0.000000	0.000000
DISTANCE(A19, M1)	100.0000	0.000000
DISTANCE(A19, M2)	0.000000	0.000000
DISTANCE(A20, M1)	4400.000	0.000000
DISTANCE(A20, M2)	0.000000	0.000000
DISTANCE(A21, M1)	60.00000	0.000000
DISTANCE(A21, M2)	0.000000	0.000000
DISTANCE(A22, M1)	2100.000	0.000000
DISTANCE(A22, M2)	0.000000	0.000000
DISTANCE(A24, M1)	1550.000	0.000000
DISTANCE(A24, M2)	0.000000	0.000000
DISTANCE(A25, M1)	1560.000	0.000000
DISTANCE(A25, M2)	0.000000	0.000000
DISTANCE(A27, M1)	1300.000	0.000000
DISTANCE(A27, M2)	0.000000	0.000000
DISTANCE(A28, M1)	930.0000	0.000000
DISTANCE(A28, M2)	0.000000	0.000000
DISTANCE(A29, M1)	1600.000	0.000000
DISTANCE(A29, M2)	0.000000	0.000000
DISTANCE(A30, M1)	1000.000	0.000000
DISTANCE(A30, M2)	0.000000	0.000000
DISTANCE(A31, M1)	3000.000	0.000000
DISTANCE(A31, M2)	0.000000	0.000000
DISTANCE(A38, M1)	1200.000	0.000000
DISTANCE(A38, M2)	0.000000	0.000000
DISTANCE(A39, M1)	1900.000	0.000000
DISTANCE(A39, M2)	0.000000	0.000000
DISTANCE(A41, M1)	50.00000	0.000000
DISTANCE(A41, M2)	0.000000	0.000000
DISTANCE(A42, M1)	50.00000	0.000000
DISTANCE(A42, M2)	0.000000	0.000000
DISTANCE(A46, M1)	1300.000	0.000000
DISTANCE(A46, M2)	0.000000	0.000000
DISTANCE(A50, M1)	4500.000	0.000000
DISTANCE(A50, M2)	0.000000	0.000000
DISTANCE(A52, M1)	3300.000	0.000000
DISTANCE(A52, M2)	0.000000	0.000000
DISTANCE(A53, M1)	3500.000	0.000000

DISTANCE(A53, M2)	0.000000	0.000000
DISTANCE(A54, M1)	1900.000	0.000000
DISTANCE(A54, M2)	0.000000	0.000000
DISTANCE(A55, M1)	3700.000	0.000000
DISTANCE(A55, M2)	0.000000	0.000000
DISTANCE(A56, M1)	1300.000	0.000000
DISTANCE(A56, M2)	0.000000	0.000000
DISTANCE(A57, M1)	2000.000	0.000000
DISTANCE(A57, M2)	0.000000	0.000000
DISTANCE(A58, M1)	5900.000	0.000000
DISTANCE(A58, M2)	0.000000	0.000000
DISTANCE(A60, M1)	2000.000	0.000000
DISTANCE(A60, M2)	0.000000	0.000000
DISTANCE(A61, M1)	4500.000	0.000000
DISTANCE(A61, M2)	0.000000	0.000000
DISTANCE(A62, M1)	3000.000	0.000000
DISTANCE(A62, M2)	0.000000	0.000000
DISTANCE(A63, M1)	4000.000	0.000000
DISTANCE(A63, M2)	0.000000	0.000000
DISTANCE(A64, M1)	2200.000	0.000000
DISTANCE(A64, M2)	0.000000	0.000000
DISTANCE(A66, M1)	3000.000	0.000000
DISTANCE(A66, M2)	0.000000	0.000000
DISTANCE(A67, M1)	1200.000	0.000000
DISTANCE(A67, M2)	0.000000	0.000000
DISTANCE(A68, M1)	200.0000	0.000000
DISTANCE(A68, M2)	0.000000	0.000000
DISTANCE(A69, M1)	3700.000	0.000000
DISTANCE(A69, M2)	0.000000	0.000000
DISTANCE(A70, M1)	1000.000	0.000000
DISTANCE(A70, M2)	0.000000	0.000000
DISTANCE(A71, M1)	4000.000	0.000000
DISTANCE(A71, M2)	0.000000	0.000000
DISTANCE(A75, M1)	900.0000	0.000000
DISTANCE(A75, M2)	0.000000	0.000000
DISTANCE(A78, M1)	400.0000	0.000000
DISTANCE(A78, M2)	0.000000	0.000000
DISTANCE(A80, M1)	3000.000	0.000000
DISTANCE(A80, M2)	0.000000	0.000000
DISTANCE(A82, M1)	4000.000	0.000000
DISTANCE(A82, M2)	0.000000	0.000000
DISTANCE(A83, M1)	4000.000	0.000000
DISTANCE(A83, M2)	0.000000	0.000000
BARREL(A1, M1)	6719.000	0.000000
BARREL(A1, M2)	0.000000	5680.000
BARREL(A3, M1)	24321.00	0.000000
BARREL(A3, M2)	0.000000	5800.000
BARREL(A4, M1)	12546.00	0.000000
BARREL(A4, M2)	0.000000	2400.000
BARREL(A7, M1)	6711.000	0.000000
BARREL(A7, M2)	0.000000	5845.000
BARREL(A8, M1)	10606.00	0.000000
BARREL(A8, M2)	0.000000	3782.000
BARREL(A11, M1)	782.0000	0.000000
BARREL(A11, M2)	0.000000	2750.000
BARREL(A13, M1)	0.000000	400.0000
BARREL(A13, M2)	9896.000	0.000000
BARREL(A14, M1)	2944.000	0.000000
BARREL(A14, M2)	0.000000	5800.000
BARREL(A15, M1)	10951.00	0.000000
BARREL(A15, M2)	0.000000	3050.000

BARREL(A16, M1)	6287.000	0.000000
BARREL(A16, M2)	0.000000	3550.000
BARREL(A17, M1)	14606.00	0.000000
BARREL(A17, M2)	0.000000	1800.000
BARREL(A19, M1)	9944.000	0.000000
BARREL(A19, M2)	0.000000	5800.000
BARREL(A20, M1)	8411.000	0.000000
BARREL(A20, M2)	0.000000	1500.000
BARREL(A21, M1)	8646.000	0.000000
BARREL(A21, M2)	0.000000	5840.000
BARREL(A22, M1)	12263.00	0.000000
BARREL(A22, M2)	0.000000	3800.000
BARREL(A24, M1)	4262.000	0.000000
BARREL(A24, M2)	0.000000	4350.000
BARREL(A25, M1)	11475.00	0.000000
BARREL(A25, M2)	0.000000	4340.000
BARREL(A27, M1)	4311.000	0.000000
BARREL(A27, M2)	0.000000	4600.000
BARREL(A28, M1)	6422.000	0.000000
BARREL(A28, M2)	0.000000	4970.000
BARREL(A29, M1)	7952.000	0.000000
BARREL(A29, M2)	0.000000	4300.000
BARREL(A30, M1)	5072.000	0.000000
BARREL(A30, M2)	0.000000	4900.000
BARREL(A31, M1)	6192.000	0.000000
BARREL(A31, M2)	0.000000	2900.000
BARREL(A38, M1)	5020.000	0.000000
BARREL(A38, M2)	0.000000	4700.000
BARREL(A39, M1)	2212.000	0.000000
BARREL(A39, M2)	0.000000	4000.000
BARREL(A41, M1)	6938.000	0.000000
BARREL(A41, M2)	0.000000	5850.000
BARREL(A42, M1)	4109.000	0.000000
BARREL(A42, M2)	0.000000	5850.000
BARREL(A46, M1)	3722.000	0.000000
BARREL(A46, M2)	0.000000	4600.000
BARREL(A50, M1)	4374.000	0.000000
BARREL(A50, M2)	0.000000	1400.000
BARREL(A52, M1)	3223.000	0.000000
BARREL(A52, M2)	0.000000	2600.000
BARREL(A53, M1)	5492.000	0.000000
BARREL(A53, M2)	0.000000	2400.000
BARREL(A54, M1)	3180.000	0.000000
BARREL(A54, M2)	0.000000	4000.000
BARREL(A55, M1)	7207.000	0.000000
BARREL(A55, M2)	0.000000	2200.000
BARREL(A56, M1)	3700.000	0.000000
BARREL(A56, M2)	0.000000	4600.000
BARREL(A57, M1)	3696.000	0.000000
BARREL(A57, M2)	0.000000	3900.000
BARREL(A58, M1)	4205.000	0.000000
BARREL(A58, M2)	23.00000	0.000000
BARREL(A60, M1)	21304.00	0.000000
BARREL(A60, M2)	0.000000	3900.000
BARREL(A61, M1)	3759.000	0.000000
BARREL(A61, M2)	0.000000	1400.000
BARREL(A62, M1)	3784.000	0.000000
BARREL(A62, M2)	0.000000	2900.000
BARREL(A63, M1)	5642.000	0.000000
BARREL(A63, M2)	0.000000	1900.000
BARREL(A64, M1)	6510.000	0.000000

BARREL(A64, M2)	0.000000	3700.000
BARREL(A66, M1)	8009.000	0.000000
BARREL(A66, M2)	0.000000	2900.000
BARREL(A67, M1)	4972.000	0.000000
BARREL(A67, M2)	0.000000	4700.000
BARREL(A68, M1)	2771.000	0.000000
BARREL(A68, M2)	0.000000	5700.000
BARREL(A69, M1)	2324.000	0.000000
BARREL(A69, M2)	0.000000	2200.000
BARREL(A70, M1)	7448.000	0.000000
BARREL(A70, M2)	0.000000	4900.000
BARREL(A71, M1)	5438.000	0.000000
BARREL(A71, M2)	0.000000	1900.000
BARREL(A75, M1)	8195.000	0.000000
BARREL(A75, M2)	0.000000	5000.000
BARREL(A78, M1)	2417.000	0.000000
BARREL(A78, M2)	0.000000	5500.000
BARREL(A80, M1)	9259.000	0.000000
BARREL(A80, M2)	0.000000	2900.000
BARREL(A82, M1)	2552.000	0.000000
BARREL(A82, M2)	0.000000	1900.000
BARREL(A83, M1)	7115.000	0.000000
BARREL(A83, M2)	0.000000	1900.000

Row	Slack or Surplus	Dual Price
1	0.7017872E+09	-1.000000
2	0.000000	-5900.000
3	0.000000	0.000000
4	0.000000	5680.000
5	0.000000	5800.000
6	0.000000	2400.000
7	0.000000	5845.000
8	0.000000	3782.000
9	0.000000	2750.000
10	0.000000	0.000000
11	0.000000	5800.000
12	0.000000	3050.000
13	0.000000	3550.000
14	0.000000	1800.000
15	0.000000	5800.000
16	0.000000	1500.000
17	0.000000	5840.000
18	0.000000	3800.000
19	0.000000	4350.000
20	0.000000	4340.000
21	0.000000	4600.000
22	0.000000	4970.000
23	0.000000	4300.000
24	0.000000	4900.000
25	0.000000	2900.000
26	0.000000	4700.000
27	0.000000	4000.000
28	0.000000	5850.000
29	0.000000	5850.000
30	0.000000	4600.000
31	0.000000	1400.000
32	0.000000	2600.000
33	0.000000	2400.000
34	0.000000	4000.000
35	0.000000	2200.000
36	0.000000	4600.000

37	0.000000	3900.000
38	0.000000	0.000000
39	0.000000	3900.000
40	0.000000	1400.000
41	0.000000	2900.000
42	0.000000	1900.000
43	0.000000	3700.000
44	0.000000	2900.000
45	0.000000	4700.000
46	0.000000	5700.000
47	0.000000	2200.000
48	0.000000	4900.000
49	0.000000	1900.000
50	0.000000	5000.000
51	0.000000	5500.000
52	0.000000	2900.000
53	0.000000	1900.000
54	0.000000	1900.000

Appendix B
ARENA Model Logic Diagrams

ARENA Model Logic Diagrams

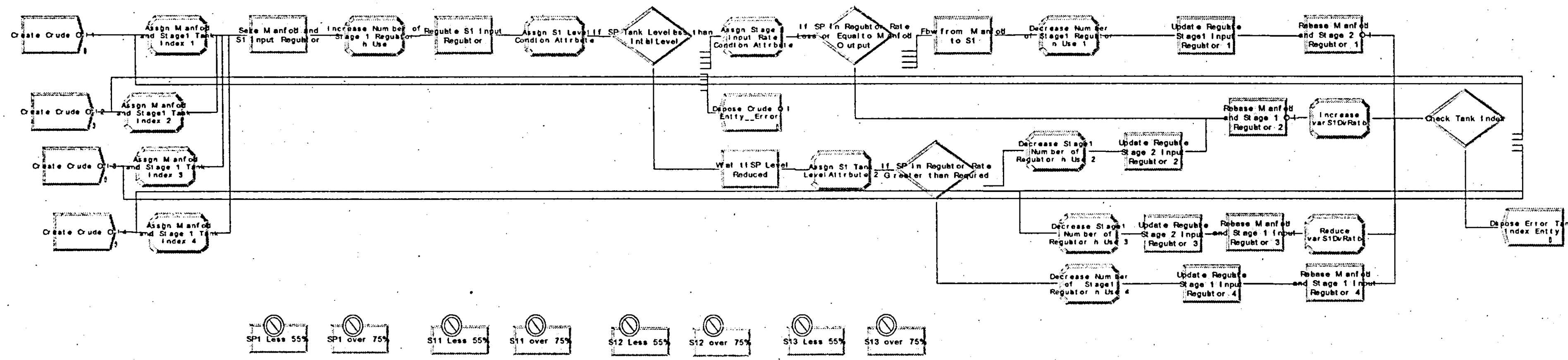


Figure 1 Model Logic of Crude Oil Separation from Manifold to Stage 1 Separators

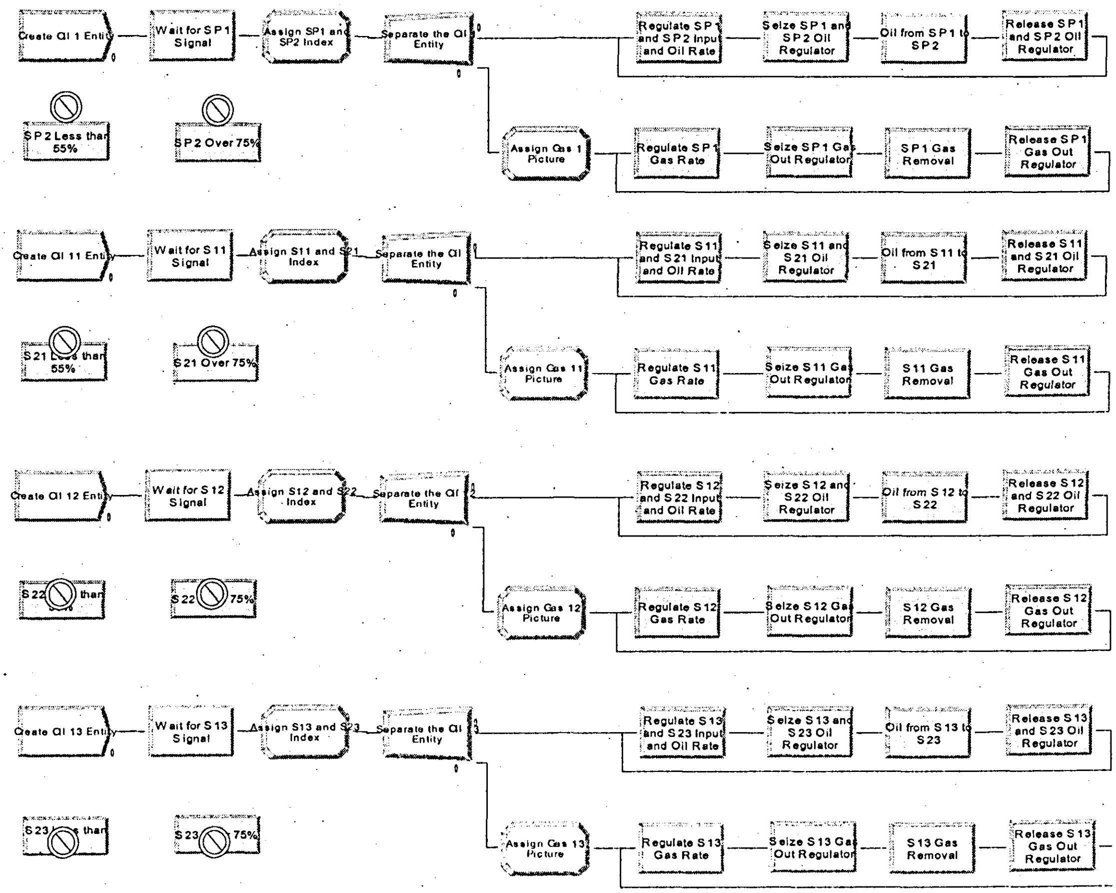


Figure 2 Model Logic of Crude Oil Separation from Stage 1 to Stage 2 Separators

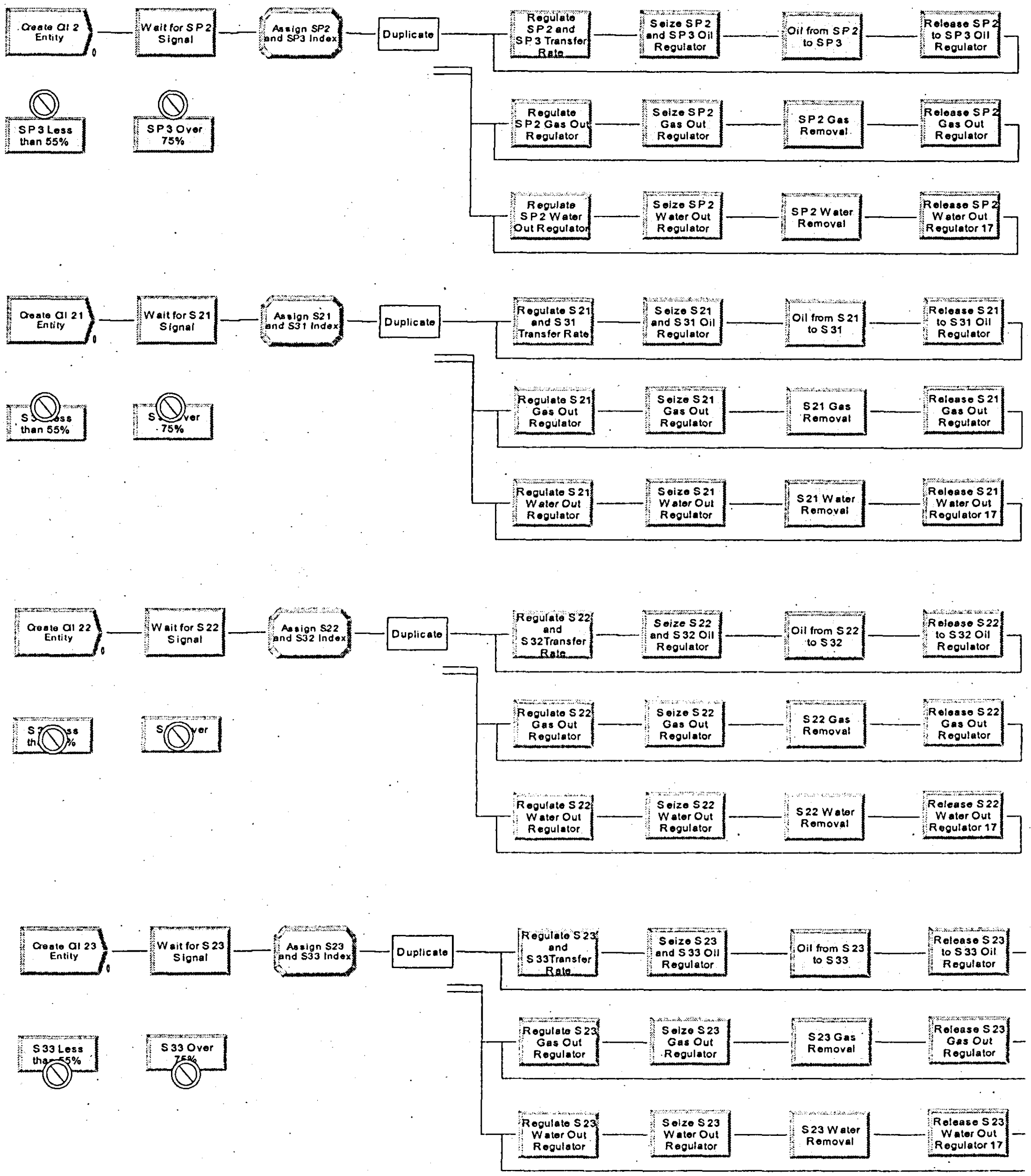


Figure 3 Model Logic of Crude Oil Separation from Stage 2 to Stage 3 Separators

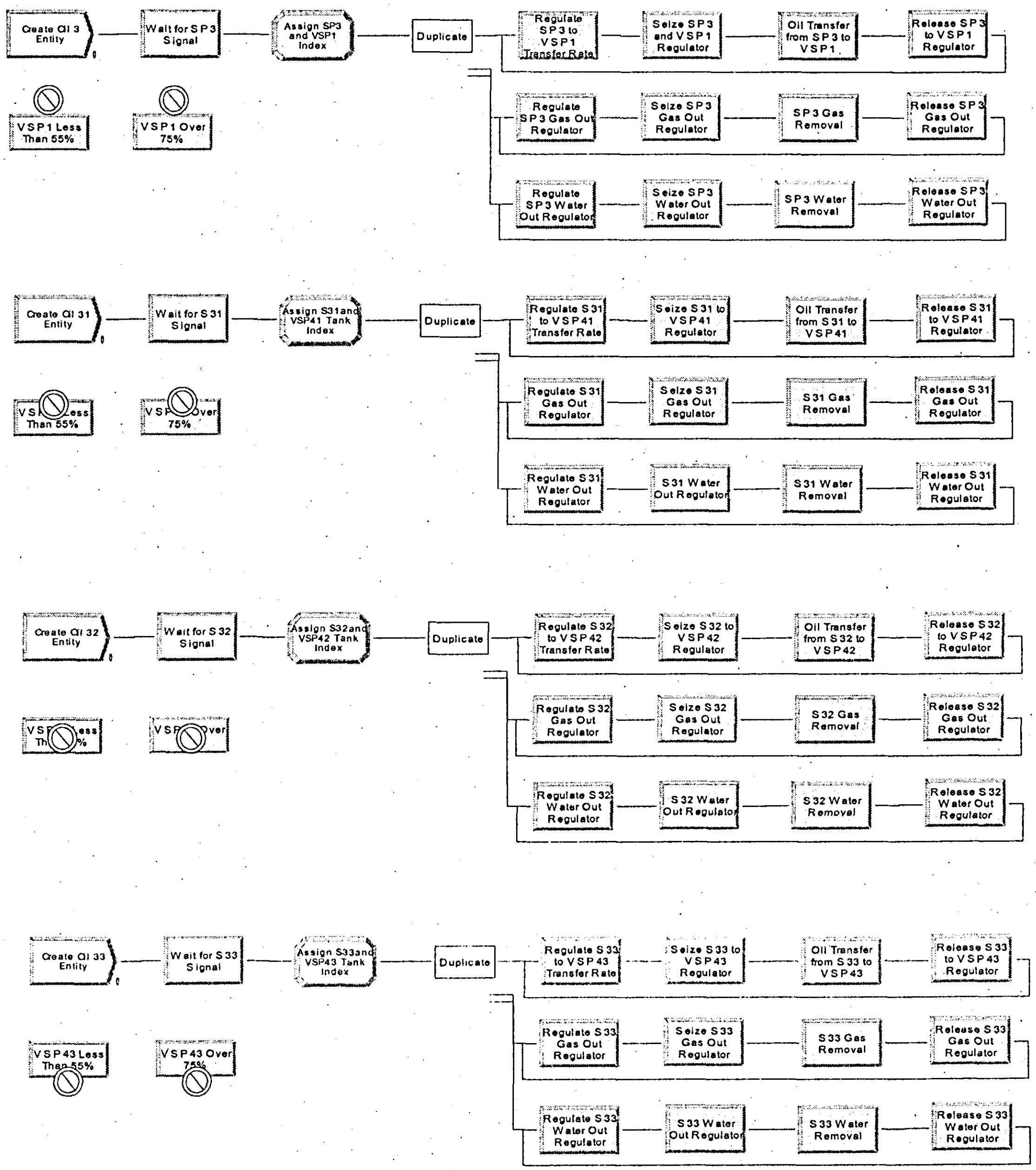


Figure 4 Model Logic of Crude Oil Separation from Stage 3 to Stage 4 Separators

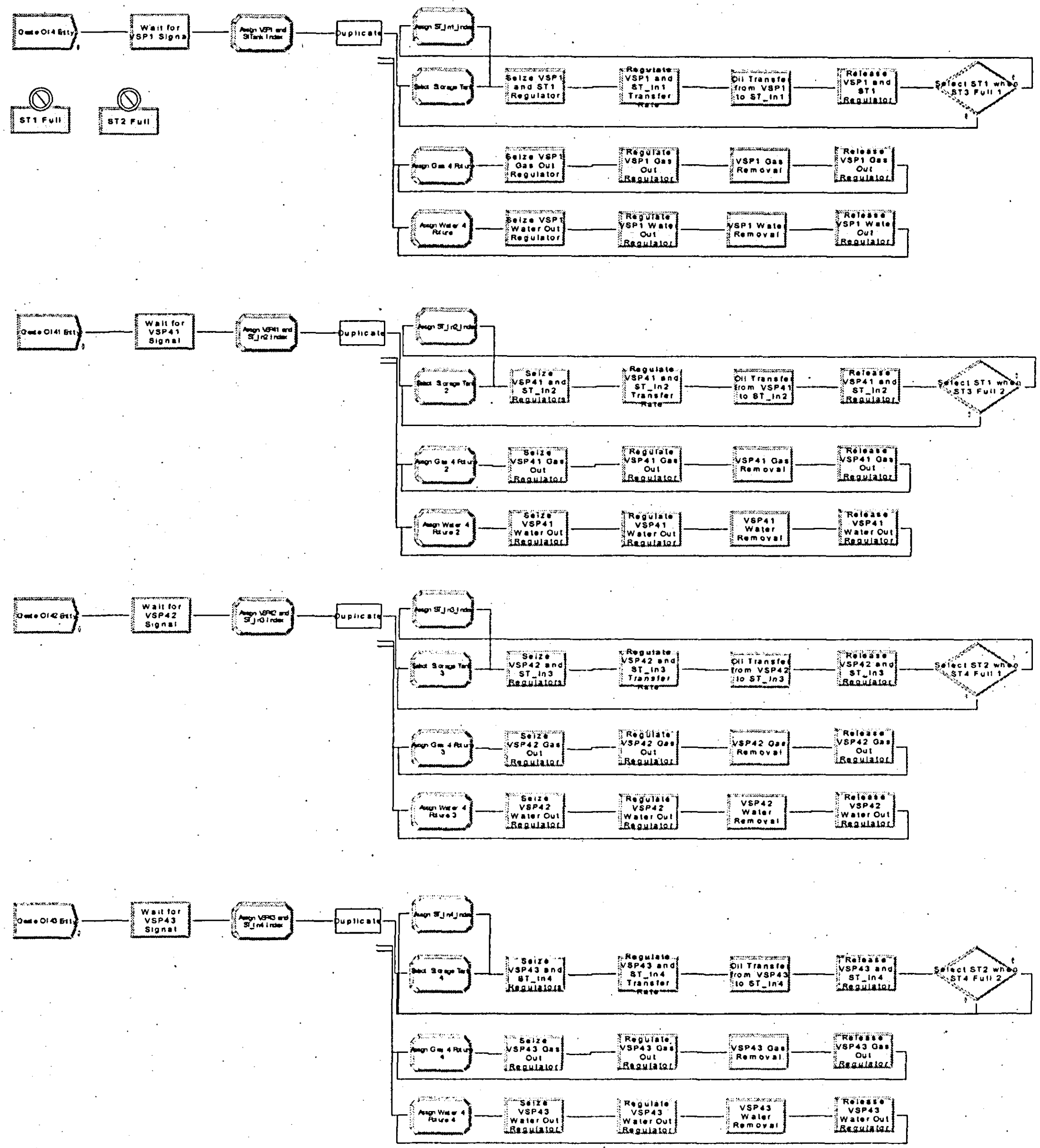


Figure 5 Model Logic of Crude Oil Separation from Stage 4 Separators to Stage 5 Storage Tank

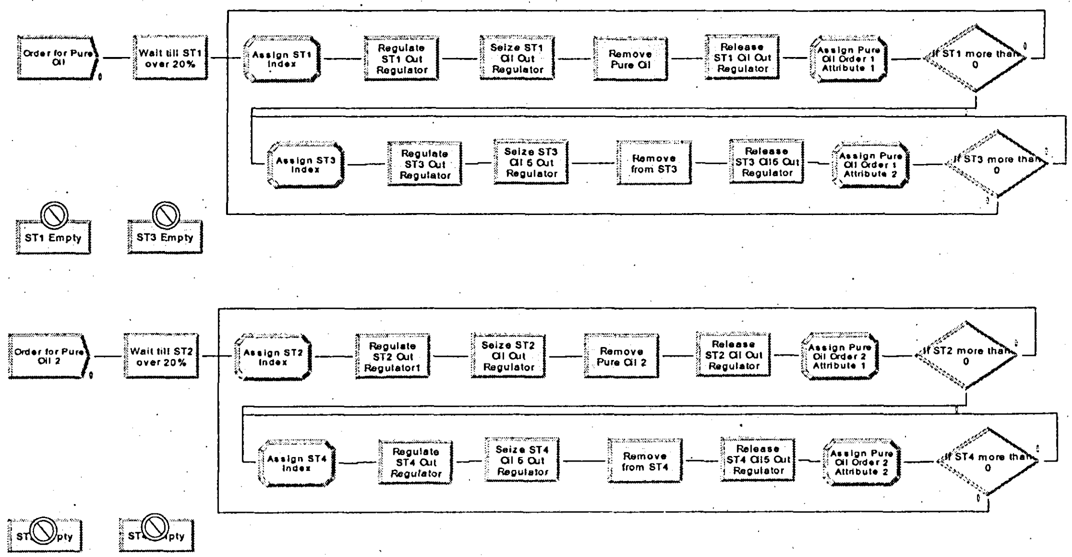


Figure 6 Model Logic of Oil Delivery from Stage 5 Oil Storage Tanks to Stage 6 Oil Centre

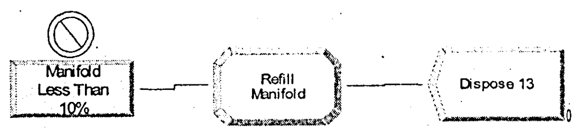


Figure 7 Model Logic of Manifold Refill

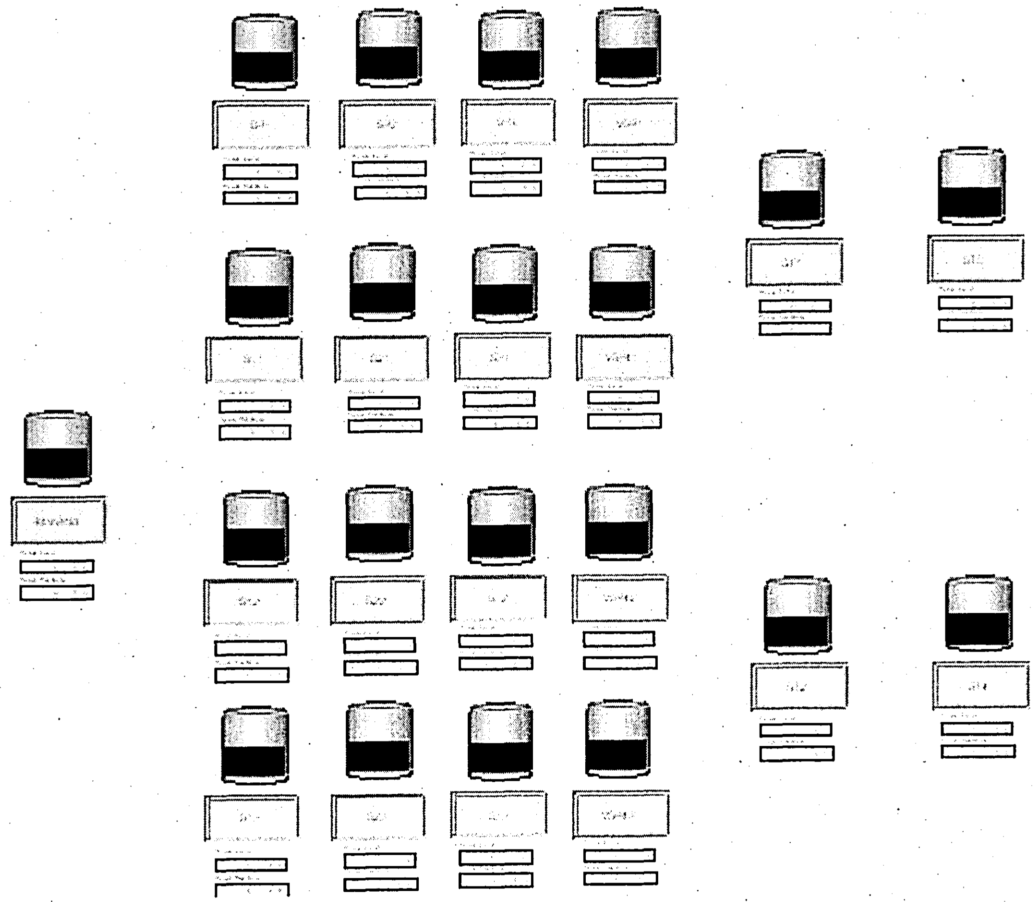


Figure 8 Tank Modules for Separators, Manifold and Storage Tanks

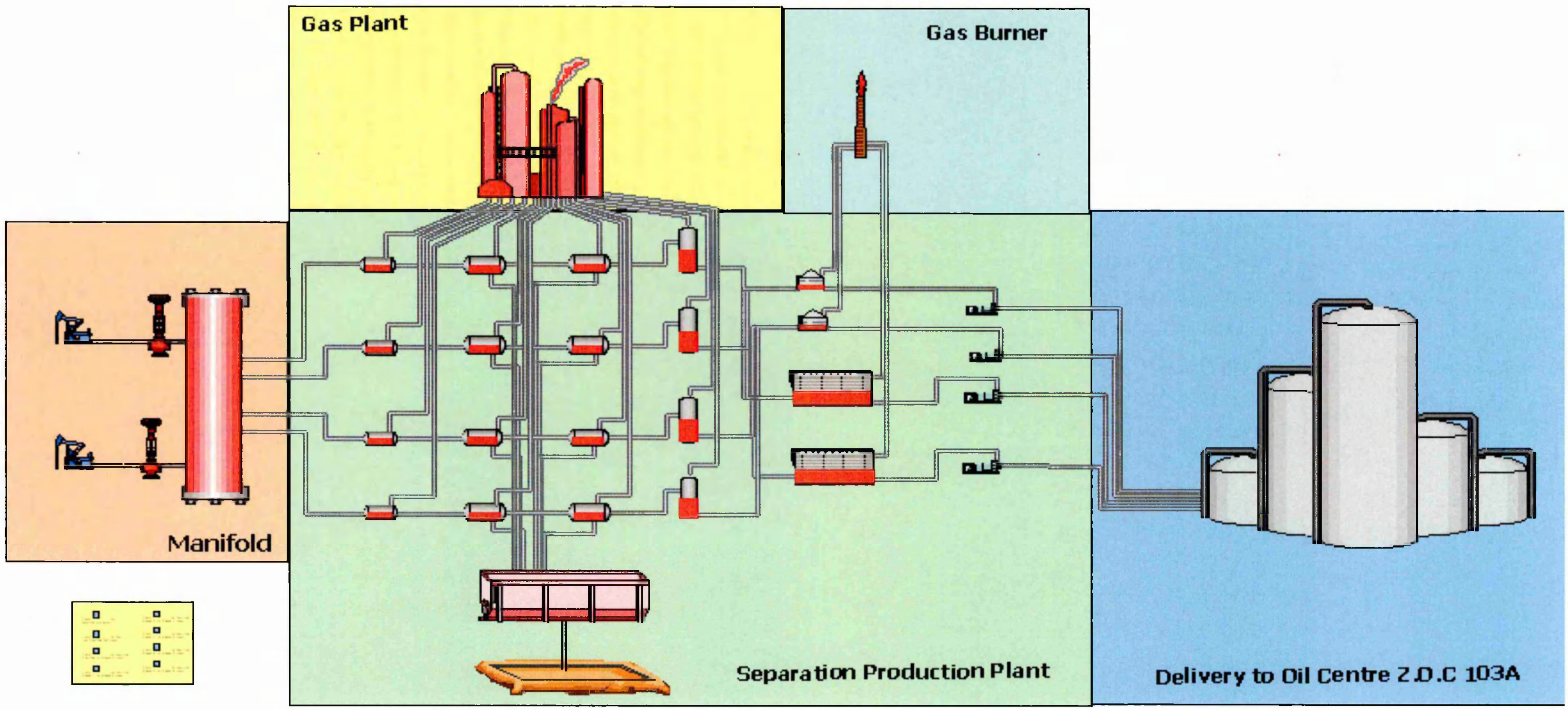


Figure 9 Animation

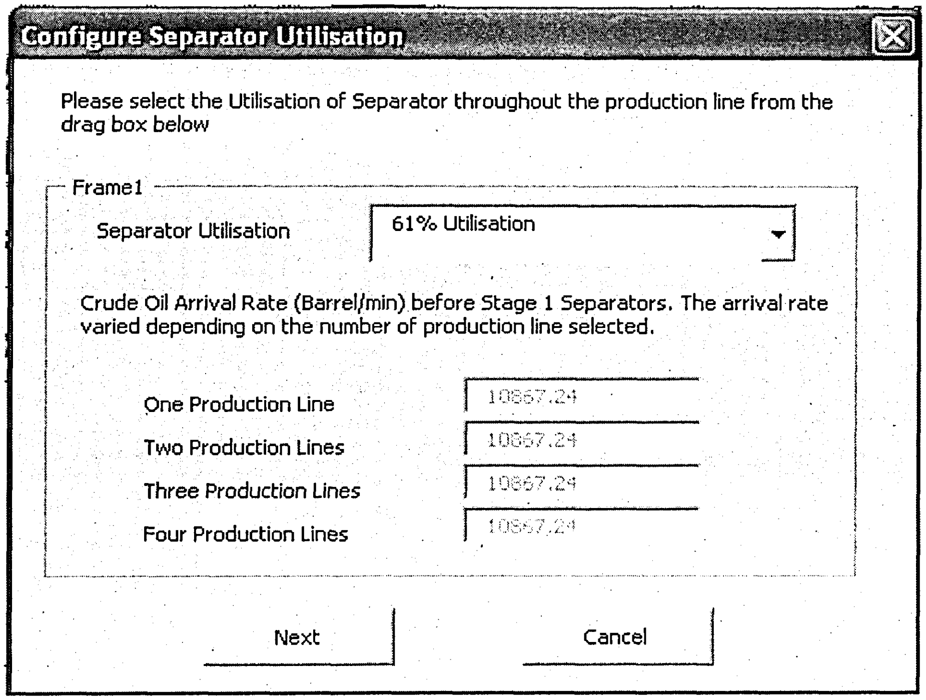


Figure 10 Interface for Changing Separators Utilisation

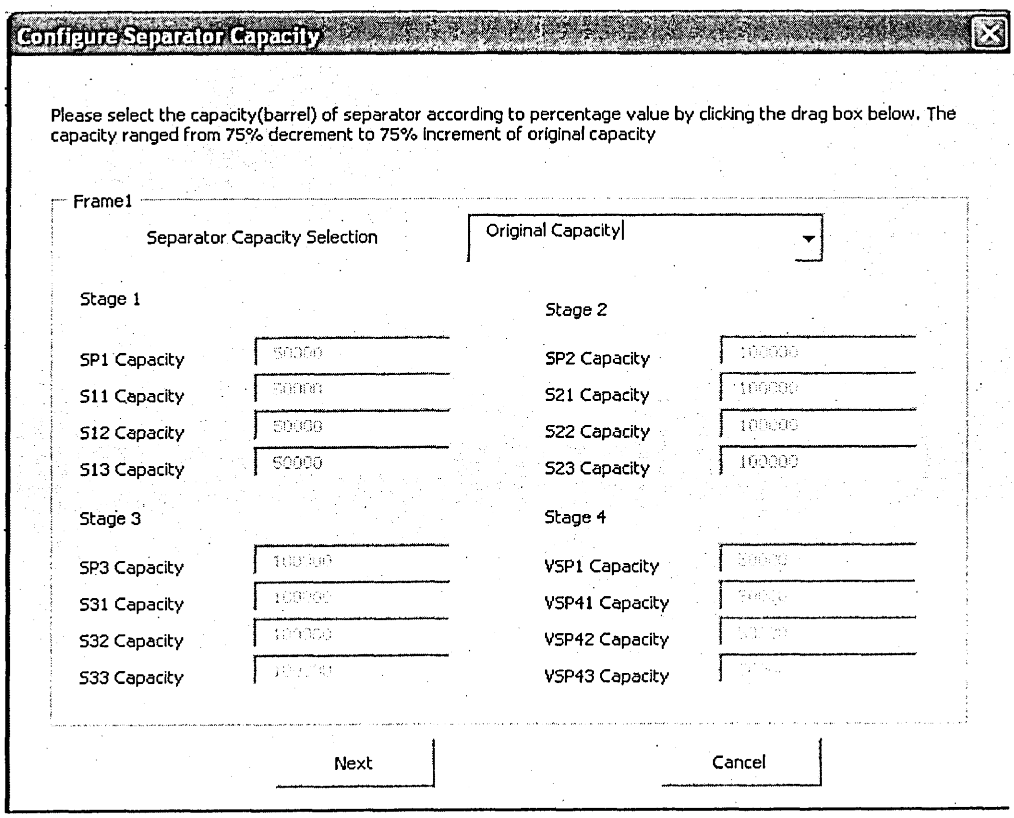


Figure 11 Interface for Changing the Capacity of the Separators

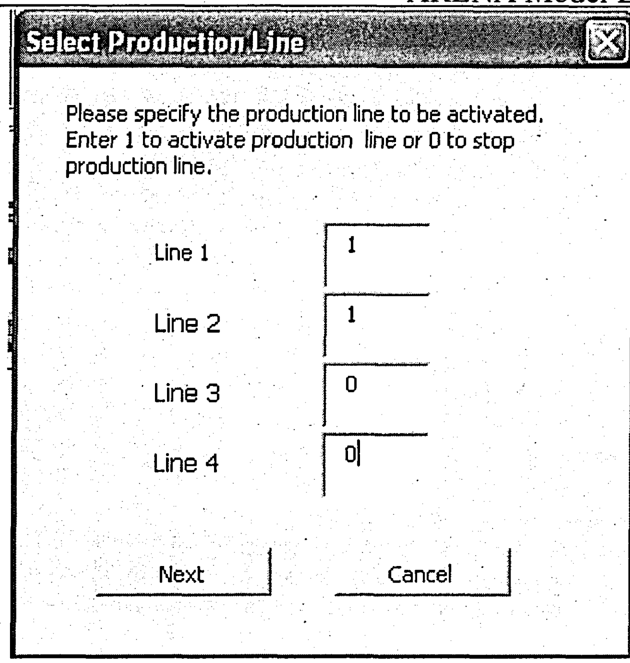


Figure 12 Interface for Selecting the Production Line

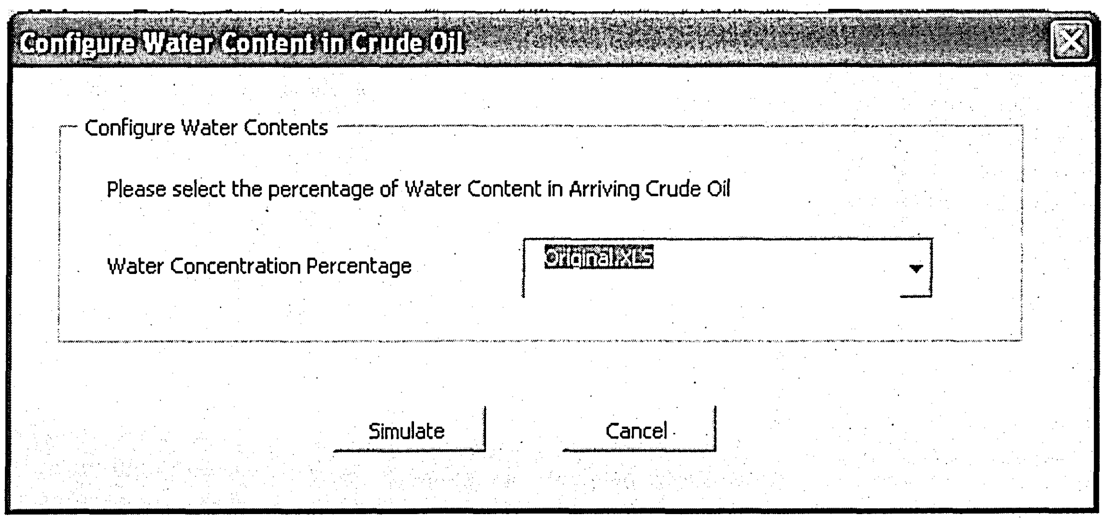


Figure 13Interface for Choosing the Water Contents in Crude Oil

Appendix C

VBA Code

Coding for Arena Objects

```
'Declaration
Dim m As Arena.Model
Dim s As Arena.SIMAN

Private Sub ModelLogic_RunBegin()

  'Show Production Line Selection Form
  frmConfigSPUtilisation.Show vbModal

End Sub

Private Sub ModelLogic_RunBeginSimulation()


  Set m = ThisDocument.Model
  Set s = m.SIMAN

  'Set the Project File Current Directory
  ProjectFileDir = Mid(m.FullName, 1, Len(m.FullName) - Len(m.Name))

  'Show Production Line Selection Form
  frmWaterConfiguration.Show vbModal

  'Stop Simulation
  If Simulate = False Then
    m.End
    Exit Sub
  End If

  'Open Excel File (XLInput)

  Set XLBook = GetObject(XLInput)
  Set XLSheet = XLBook.Worksheets("Arena Input Data")

  'Read the Oil Content Variable from Excel
  varOil1Ratio = s.SymbolNumber("varOil1Ratio")
  s.VariableArrayValue(varOil1Ratio) = XLSheet.Range("B31")

  varOil2Ratio = s.SymbolNumber("varOil2Ratio")
  s.VariableArrayValue(varOil2Ratio) = XLSheet.Range("B32")
```

```
varOil3Ratio = s.SymbolNumber("varOil3Ratio")
  s.VariableArrayValue(varOil3Ratio) = XLSheet.Range("B33")

  varOil4Ratio = s.SymbolNumber("varOil4Ratio")
  s.VariableArrayValue(varOil4Ratio) = XLSheet.Range("B34")

  'Read the Gas Content Variable from Excel
  varGas1Ratio = s.SymbolNumber("varGas1Ratio")
  s.VariableArrayValue(varGas1Ratio) = XLSheet.Range("B35")

  varGas2Ratio = s.SymbolNumber("varGas2Ratio")
  s.VariableArrayValue(varGas2Ratio) = XLSheet.Range("B36")

  varGas3Ratio = s.SymbolNumber("varGas3Ratio")
  s.VariableArrayValue(varGas3Ratio) = XLSheet.Range("B37")

  varGas4Ratio = s.SymbolNumber("varGas4Ratio")
  s.VariableArrayValue(varGas4Ratio) = XLSheet.Range("B38")

  'Read the Water Content Variable from Excel (No water for Stage 1)
  varWater2Ratio = s.SymbolNumber("varWater2Ratio")
  s.VariableArrayValue(varWater2Ratio) = XLSheet.Range("B39")

  varWater3Ratio = s.SymbolNumber("varWater3Ratio")
  s.VariableArrayValue(varWater3Ratio) = XLSheet.Range("B40")


End Sub

Private Sub ModelLogic_RunEnd()

End Sub
```

Coding for Configuring Separator Capacity Interface Form

```
Private Sub cboAllCapacity_Change()

    Select Case cboAllCapacity.Text
        Case "Original Capacity"
            txbSP1.Text = "50000"
            txbS11.Text = "50000"
            txbS12.Text = "50000"
            txbS13.Text = "50000"

            txbSP2.Text = "100000"
            txbS21.Text = "100000"
            txbS22.Text = "100000"
            txbS23.Text = "100000"

            txbSP3.Text = "100000"
            txbS31.Text = "100000"
            txbS32.Text = "100000"
            txbS33.Text = "100000"

            txbVSP1.Text = "50000"
            txbVSP41.Text = "50000"
            txbVSP42.Text = "50000"
            txbVSP43.Text = "50000"

        '5% Capacity Increment
        Case "Increase 5% Capacity"
            txbSP1.Text = "52500"
            txbS11.Text = "52500"
            txbS12.Text = "52500"
            txbS13.Text = "52500"

            txbSP2.Text = "105000"
            txbS21.Text = "105000"
            txbS22.Text = "105000"
            txbS23.Text = "105000"

            txbSP3.Text = "105000"
            txbS31.Text = "105000"
            txbS32.Text = "105000"
            txbS33.Text = "105000"

            txbVSP1.Text = "52500"
            txbVSP41.Text = "52500"
            txbVSP42.Text = "52500"
            txbVSP43.Text = "52500"
```

```
'10% Capacity Increment
    Case "Increase 10% Capacity"
        txbSP1.Text = "55000"
        txbS11.Text = "55000"
        txbS12.Text = "55000"
        txbS13.Text = "55000"

        txbSP2.Text = "110000"
        txbS21.Text = "110000"
        txbS22.Text = "110000"
        txbS23.Text = "110000"

        txbSP3.Text = "110000"
        txbS31.Text = "110000"
        txbS32.Text = "110000"
        txbS33.Text = "110000"


        txbVSP1.Text = "55000"
        txbVSP41.Text = "55000"
        txbVSP42.Text = "55000"
        txbVSP43.Text = "55000"

    '20% Capacity Increment
    Case "Increase 20% Capacity"
        txbSP1.Text = "60000"
        txbS11.Text = "60000"
        txbS12.Text = "60000"
        txbS13.Text = "60000"

        txbSP2.Text = "125000"
        txbS21.Text = "125000"
        txbS22.Text = "125000"
        txbS23.Text = "125000"

        txbSP3.Text = "125000"
        txbS31.Text = "125000"
        txbS32.Text = "125000"
        txbS33.Text = "125000"

        txbVSP1.Text = "60000"
        txbVSP41.Text = "60000"
        txbVSP42.Text = "60000"
        txbVSP43.Text = "60000"
```

```
'35% Capacity Increment
    Case "Increase 35% Capacity"
        txbSP1.Text = "67500"
        txbS11.Text = "67500"
        txbS12.Text = "67500"
        txbS13.Text = "67500"

        txbSP2.Text = "135000"
        txbS21.Text = "135000"
        txbS22.Text = "135000"
        txbS23.Text = "135000"

        txbSP3.Text = "135000"
        txbS31.Text = "135000"
        txbS32.Text = "135000"
        txbS33.Text = "135000"

        txbVSP1.Text = "67500"
        txbVSP41.Text = "67500"
        txbVSP42.Text = "67500"
        txbVSP43.Text = "67500"


'50% Capacity Increment
    Case "Increase 50% Capacity"
        txbSP1.Text = "75000"
        txbS11.Text = "75000"
        txbS12.Text = "75000"
        txbS13.Text = "75000"

        txbSP2.Text = "150000"
        txbS21.Text = "150000"
        txbS22.Text = "150000"
        txbS23.Text = "150000"

        txbSP3.Text = "150000"
        txbS31.Text = "150000"
        txbS32.Text = "150000"
        txbS33.Text = "150000"

        txbVSP1.Text = "75000"
        txbVSP41.Text = "75000"
        txbVSP42.Text = "75000"
        txbVSP43.Text = "75000"
```

```
'75% Capacity Increment
    Case "Increase 75% Capacity"
      txbSP1.Text = "87500"
      txbS11.Text = "87500"
      txbS12.Text = "87500"
      txbS13.Text = "87500"

      txbSP2.Text = "175000"
      txbS21.Text = "175000"
      txbS22.Text = "175000"
      txbS23.Text = "175000"

      txbSP3.Text = "175000"
      txbS31.Text = "175000"
      txbS32.Text = "175000"
      txbS33.Text = "175000"

      txbVSP1.Text = "87500"
      txbVSP41.Text = "87500"
      txbVSP42.Text = "87500"
      txbVSP43.Text = "87500"

'Capacity Reduction
    '5% Capacity Reduction
    Case "Reduce 5% Capacity"
      txbSP1.Text = "47500"
      txbS11.Text = "47500"
      txbS12.Text = "47500"
      txbS13.Text = "47500"

      txbSP2.Text = "95000"
      txbS21.Text = "95000"
      txbS22.Text = "95000"
      txbS23.Text = "95000"

      txbSP3.Text = "95000"
      txbS31.Text = "95000"
      txbS32.Text = "95000"
      txbS33.Text = "95000"

      txbVSP1.Text = "47500"
      txbVSP41.Text = "47500"
      txbVSP42.Text = "47500"
      txbVSP43.Text = "47500"
```

```
'10% Capacity Reduction
    Case "Reduce 10% Capacity"
        txbSP1.Text = "45000"
        txbS11.Text = "45000"
        txbS12.Text = "45000"
        txbS13.Text = "45000"

        txbSP2.Text = "90000"
        txbS21.Text = "90000"
        txbS22.Text = "90000"
        txbS23.Text = "90000"

        txbSP3.Text = "90000"
        txbS31.Text = "90000"
        txbS32.Text = "90000"
        txbS33.Text = "90000"

        txbVSP1.Text = "45000"
        txbVSP41.Text = "45000"
        txbVSP42.Text = "45000"
        txbVSP43.Text = "45000"

'20% Capacity Reduction
    Case "Reduce 20% Capacity"
        txbSP1.Text = "40000"
        txbS11.Text = "40000"
        txbS12.Text = "40000"
        txbS13.Text = "40000"

        txbSP2.Text = "80000"
        txbS21.Text = "80000"
        txbS22.Text = "80000"
        txbS23.Text = "80000"

        txbSP3.Text = "80000"
        txbS31.Text = "80000"
        txbS32.Text = "80000"
        txbS33.Text = "80000"

        txbVSP1.Text = "40000"
        txbVSP41.Text = "40000"
        txbVSP42.Text = "40000"
        txbVSP43.Text = "40000"
```

```
'35% Capacity Reduction
    Case "Reduce 35% Capacity"
        txbSP1.Text = "32500"
        txbS11.Text = "32500"
        txbS12.Text = "32500"
        txbS13.Text = "32500"

        txbSP2.Text = "65000"
        txbS21.Text = "65000"
        txbS22.Text = "65000"
        txbS23.Text = "65000"

        txbSP3.Text = "65000"
        txbS31.Text = "65000"
        txbS32.Text = "65000"
        txbS33.Text = "65000"

        txbVSP1.Text = "32500"
        txbVSP41.Text = "32500"
        txbVSP42.Text = "32500"
        txbVSP43.Text = "32500"

'50% Capacity Reduction
    Case "Reduce 50% Capacity"
        txbSP1.Text = "25000"
        txbS11.Text = "25000"
        txbS12.Text = "25000"
        txbS13.Text = "25000"
        txbSP2.Text = "50000"
        txbS21.Text = "50000"
        txbS22.Text = "50000"
        txbS23.Text = "50000"

        txbSP3.Text = "50000"
        txbS31.Text = "50000"
        txbS32.Text = "50000"
        txbS33.Text = "50000"

        txbVSP1.Text = "25000"
        txbVSP41.Text = "25000"
        txbVSP42.Text = "25000"
        txbVSP43.Text = "25000"
```

```
'75% Capacity Reduction
    Case "Reduce 75% Capacity"
      txbSP1.Text = "12500"
      txbS11.Text = "12500"
      txbS12.Text = "12500"
      txbS13.Text = "12500"

      txbSP2.Text = "25000"
      txbS21.Text = "25000"
      txbS22.Text = "25000"
      txbS23.Text = "25000"

      txbSP3.Text = "25000"
      txbS31.Text = "25000"
      txbS32.Text = "25000"
      txbS33.Text = "25000"

      txbVSP1.Text = "12500"
      txbVSP41.Text = "12500"
      txbVSP42.Text = "12500"
      txbVSP43.Text = "12500"
  End Select
End Sub
```

```
Private Sub cmdCancel2_Click()

    Simulate = False
    Unload frmConfigSPCap

    Set m = ThisDocument.Model
    Set s = m.SIMAN

    'End the model run.
    m.End

End Sub

Private Sub cmdNext_Click()

'Apply Capacity Data or Set Method for Property Construction
Dim mdl As Arena.module
Dim mdls As Arena.modules
Set mdls = ActiveModel.modules

    'SP1
    Set mdl = mdls(mdls.Find(smFindTag, "SP1"))     'find SP1 Tank Module
    Select Case cboAllCapacity.Text
        Case "Orignal Capacity"
            mdl.Data("Capacity") = 1
        Case "Increase 5% Capacity"
            mdl.Data("Capacity") = 2
        Case "Increase 10% Capacity"
            mdl.Data("Capacity") = 3
        Case "Increase 20% Capacity"
            mdl.Data("Capacity") = 4
        Case "Increase 35% Capacity"
            mdl.Data("Capacity") = 5
        Case "Increase 50% Capacity"
            mdl.Data("Capacity") = 6
        Case "Increase 75% Capacity"
            mdl.Data("Capacity") = 7
    End Select

    Set mdl = mdls(mdls.Find(smFindTag, "SP1"))
        mdl.Data("Capacity") = txbSP1.Text
```

```
'S11
Set mdl = mdls(mdls.Find(smFindTag, "S11"))    'find module
Select Case cboAllCapacity.Text
   Case "Orignal Capacity"
      mdl.Data("Capacity") = 1
   Case "Increase 5% Capacity"
      mdl.Data("Capacity") = 2
   Case "Increase 10% Capacity"
      mdl.Data("Capacity") = 3
   Case "Increase 20% Capacity"
      mdl.Data("Capacity") = 4
   Case "Increase 35% Capacity"
      mdl.Data("Capacity") = 5
   Case "Increase 50% Capacity"
      mdl.Data("Capacity") = 6
   Case "Increase 75% Capacity"
      mdl.Data("Capacity") = 7
End Select

Set mdl = mdls(mdls.Find(smFindTag, "S11"))
   mdl.Data("Capacity") = txbS11.Text

'S12
Set mdl = mdls(mdls.Find(smFindTag, "S12"))    'find module
Select Case cboAllCapacity.Text
   Case "Orignal Capacity"
      mdl.Data("Capacity") = 1
   Case "Increase 5% Capacity"
      mdl.Data("Capacity") = 2
   Case "Increase 10% Capacity"
      mdl.Data("Capacity") = 3
   Case "Increase 20% Capacity"
      mdl.Data("Capacity") = 4
   Case "Increase 35% Capacity"
      mdl.Data("Capacity") = 5
   Case "Increase 50% Capacity"
      mdl.Data("Capacity") = 6
   Case "Increase 75% Capacity"
      mdl.Data("Capacity") = 7
End Select

Set mdl = mdls(mdls.Find(smFindTag, "S12"))
   mdl.Data("Capacity") = txbS12.Text
```

```
'S13
 Set mdl = mdls(mdls.Find(smFindTag, "S13"))    'find module
 Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
       mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
       mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
       mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
       mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
       mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
       mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
       mdl.Data("Capacity") = 7
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S13"))
    mdl.Data("Capacity") = txbS13.Text

'SP2
 Set mdl = mdls(mdls.Find(smFindTag, "SP2"))    'find module
 Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
       mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
       mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
       mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
       mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
       mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
       mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
       mdl.Data("Capacity") = 7
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "SP2"))
    mdl.Data("Capacity") = txbSP2.Text
```

```
'S21
 Set mdl = mdls(mdls.Find(smFindTag, "S21"))     'find module
 Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
       mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
       mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
       mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
       mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
       mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
       mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
       mdl.Data("Capacity") = 7
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S21"))
    mdl.Data("Capacity") = txbS21.Text

 'S22
 Set mdl = mdls(mdls.Find(smFindTag, "S22"))     'find module
 Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
       mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
       mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
       mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
       mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
       mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
       mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
       mdl.Data("Capacity") = 7
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S22"))
    mdl.Data("Capacity") = txbS22.Text
```

```
'S23
 Set mdl = mdls(mdls.Find(smFindTag, "S23"))     'find module
 Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
       mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
       mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
       mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
       mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
       mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
       mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
       mdl.Data("Capacity") = 7
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S23"))
    mdl.Data("Capacity") = txbS23.Text

 'SP3
 Set mdl = mdls(mdls.Find(smFindTag, "SP3"))     'find module
 Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
       mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
       mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
       mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
       mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
       mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
       mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
       mdl.Data("Capacity") = 7
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "SP3"))
    mdl.Data("Capacity") = txbSP3.Text
```

```
'S31
  Set mdl = mdls(mdls.Find(smFindTag, "S31"))     'find module
  Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
      mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
      mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
      mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
      mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
      mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
      mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
      mdl.Data("Capacity") = 7
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "S31"))
    mdl.Data("Capacity") = txbS31.Text

  'S32
  Set mdl = mdls(mdls.Find(smFindTag, "S32"))     'find module
  Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
      mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
      mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
      mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
      mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
      mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
      mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
      mdl.Data("Capacity") = 7
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "S32"))
    mdl.Data("Capacity") = txbS32.Text
```

```
'S33
 Set mdl = mdls(mdls.Find(smFindTag, "S33"))     'find module
 Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
       mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
       mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
       mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
       mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
       mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
       mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
       mdl.Data("Capacity") = 7
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S33"))
    mdl.Data("Capacity") = txbS33.Text

 'VSP1
 Set mdl = mdls(mdls.Find(smFindTag, "VSP1"))     'find module
 Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
       mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
       mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
       mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
       mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
       mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
       mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
       mdl.Data("Capacity") = 7
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "VSP1"))
    mdl.Data("Capacity") = txbVSP1.Text
```

```
'VSP41
  Set mdl = mdls(mdls.Find(smFindTag, "VSP41"))    'find module
  Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
      mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
      mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
      mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
      mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
      mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
      mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
      mdl.Data("Capacity") = 7
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "VSP41"))
    mdl.Data("Capacity") = txbVSP41.Text

  'VSP42
  Set mdl = mdls(mdls.Find(smFindTag, "VSP42"))    'find module
  Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
      mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
      mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
      mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
      mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
      mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
      mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
      mdl.Data("Capacity") = 7
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "VSP42"))
    mdl.Data("Capacity") = txbVSP42.Text
```

```
'VSP43
 Set mdl = mdls(mdls.Find(smFindTag, "VSP43"))    'find module
 Select Case cboAllCapacity.Text
    Case "Orignal Capacity"
       mdl.Data("Capacity") = 1
    Case "Increase 5% Capacity"
       mdl.Data("Capacity") = 2
    Case "Increase 10% Capacity"
       mdl.Data("Capacity") = 3
    Case "Increase 20% Capacity"
       mdl.Data("Capacity") = 4
    Case "Increase 35% Capacity"
       mdl.Data("Capacity") = 5
    Case "Increase 50% Capacity"
       mdl.Data("Capacity") = 6
    Case "Increase 75% Capacity"
       mdl.Data("Capacity") = 7
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "VSP43"))
    mdl.Data("Capacity") = txbVSP43.Text


 Simulate = False

 'Unload the form
 Unload frmConfigSPCap

 'Load Production Line Form
 frmProdLine.Show vbModal


End Sub

Private Sub UserForm_Initialize()
On Error GoTo ErrorOccurred
```

```
'Setup Combo-box Lists
cboAllCapacity.AddItem "Original Capacity"
cboAllCapacity.AddItem "Increase 5% Capacity"
cboAllCapacity.AddItem "Increase 10% Capacity"
cboAllCapacity.AddItem "Increase 20% Capacity"
cboAllCapacity.AddItem "Increase 35% Capacity"
cboAllCapacity.AddItem "Increase 50% Capacity"
cboAllCapacity.AddItem "Increase 75% Capacity"
cboAllCapacity.AddItem "Reduce 5% Capacity"
cboAllCapacity.AddItem "Reduce 10% Capacity"
cboAllCapacity.AddItem "Reduce 20% Capacity"
cboAllCapacity.AddItem "Reduce 35% Capacity"
cboAllCapacity.AddItem "Reduce 50% Capacity"
cboAllCapacity.AddItem "Reduce 75% Capacity"

'Apply Capacity Data
Dim mdl As Arena.module
Dim mdls As Arena.modules
Set mdls = ActiveModel.modules

  'SP1
  Set mdl = mdls(mdls.Find(smFindTag, "SP1"))     'find module
  Select Case mdl.Data("Capacity")
    Case 1
    cboAllCapacity.Text = "Original Capacity"
    Case 2
    cboAllCapacity.Text = "Increase 5% Capacity"
    Case 3
    cboAllCapacity.Text = "Increase 10% Capacity"
    Case 4
    cboAllCapacity.Text = "Increase 20% Capacity"
    Case 5
    cboAllCapacity.Text = "Increase 35% Capacity"
    Case 6
    cboAllCapacity.Text = "Increase 50% Capacity"
    Case 7
    cboAllCapacity.Text = "Increase 75% Capacity"
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "SP1"))
  mdl.Data("Capacity") = txbSP1.Text
```

```
'S11
  Set mdl = mdls(mdls.Find(smFindTag, "S11"))     'find module
  Select Case mdl.Data("Capacity")
     Case 1
     cboAllCapacity.Text = "Original Capacity"
     Case 2
     cboAllCapacity.Text = "Increase 5% Capacity"
     Case 3
     cboAllCapacity.Text = "Increase 10% Capacity"
     Case 4
     cboAllCapacity.Text = "Increase 20% Capacity"
     Case 5
     cboAllCapacity.Text = "Increase 35% Capacity"
     Case 6
     cboAllCapacity.Text = "Increase 50% Capacity"
     Case 7
     cboAllCapacity.Text = "Increase 75% Capacity"
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "S11"))
  mdl.Data("Capacity") = txbS11.Text

  'S12
  Set mdl = mdls(mdls.Find(smFindTag, "S12"))     'find module
  Select Case mdl.Data("Capacity")
     Case 1
     cboAllCapacity.Text = "Original Capacity"
     Case 2
     cboAllCapacity.Text = "Increase 5% Capacity"
     Case 3
     cboAllCapacity.Text = "Increase 10% Capacity"
     Case 4
     cboAllCapacity.Text = "Increase 20% Capacity"
     Case 5
     cboAllCapacity.Text = "Increase 35% Capacity"
     Case 6
     cboAllCapacity.Text = "Increase 50% Capacity"
     Case 7
     cboAllCapacity.Text = "Increase 75% Capacity"
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "S12"))
  mdl.Data("Capacity") = txbS12.Text
```

```
'S13
 Set mdl = mdls(mdls.Find(smFindTag, "S13"))     'find module
 Select Case mdl.Data("Capacity")
    Case 1
    cboAllCapacity.Text = "Original Capacity"
    Case 2
    cboAllCapacity.Text = "Increase 5% Capacity"
    Case 3
    cboAllCapacity.Text = "Increase 10% Capacity"
    Case 4
    cboAllCapacity.Text = "Increase 20% Capacity"
    Case 5
    cboAllCapacity.Text = "Increase 35% Capacity"
    Case 6
    cboAllCapacity.Text = "Increase 50% Capacity"
    Case 7
    cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S13"))
 mdl.Data("Capacity") = txbS13.Text

 'SP2
 Set mdl = mdls(mdls.Find(smFindTag, "SP2"))     'find module
 Select Case mdl.Data("Capacity")
    Case 1
    cboAllCapacity.Text = "Original Capacity"
    Case 2
    cboAllCapacity.Text = "Increase 5% Capacity"
    Case 3
    cboAllCapacity.Text = "Increase 10% Capacity"
    Case 4
    cboAllCapacity.Text = "Increase 20% Capacity"
    Case 5
    cboAllCapacity.Text = "Increase 35% Capacity"
    Case 6
    cboAllCapacity.Text = "Increase 50% Capacity"
    Case 7
    cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "SP2"))
 mdl.Data("Capacity") = txbSP2.Text
```

```
'S21
  Set mdl = mdls(mdls.Find(smFindTag, "S21"))     'find module
  Select Case mdl.Data("Capacity")
     Case 1
     cboAllCapacity.Text = "Original Capacity"
     Case 2
     cboAllCapacity.Text = "Increase 5% Capacity"
     Case 3
     cboAllCapacity.Text = "Increase 10% Capacity"
     Case 4
     cboAllCapacity.Text = "Increase 20% Capacity"
     Case 5
     cboAllCapacity.Text = "Increase 35% Capacity"
     Case 6
     cboAllCapacity.Text = "Increase 50% Capacity"
     Case 7
     cboAllCapacity.Text = "Increase 75% Capacity"
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "S21"))
  mdl.Data("Capacity") = txbS21.Text
```

```
'S22
 Set mdl = mdls(mdls.Find(smFindTag, "S22"))     'find module
 Select Case mdl.Data("Capacity")
    Case 1
    cboAllCapacity.Text = "Original Capacity"
    Case 2
    cboAllCapacity.Text = "Increase 5% Capacity"
    Case 3
    cboAllCapacity.Text = "Increase 10% Capacity"
    Case 4
    cboAllCapacity.Text = "Increase 20% Capacity"
    Case 5
    cboAllCapacity.Text = "Increase 35% Capacity"
    Case 6
    cboAllCapacity.Text = "Increase 50% Capacity"
    Case 7
    cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S22"))
 mdl.Data("Capacity") = txbS22.Text

 'S23
 Set mdl = mdls(mdls.Find(smFindTag, "S23"))     'find module
 Select Case mdl.Data("Capacity")
    Case 1
    cboAllCapacity.Text = "Original Capacity"
    Case 2
    cboAllCapacity.Text = "Increase 5% Capacity"
    Case 3
    cboAllCapacity.Text = "Increase 10% Capacity"
    Case 4
    cboAllCapacity.Text = "Increase 20% Capacity"
    Case 5
    cboAllCapacity.Text = "Increase 35% Capacity"
    Case 6
    cboAllCapacity.Text = "Increase 50% Capacity"
    Case 7
    cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S23"))
 mdl.Data("Capacity") = txbS23.Text
```

```
'SP3
 Set mdl = mdls(mdls.Find(smFindTag, "SP3"))    'find module
 Select Case mdl.Data("Capacity")
    Case 1
    cboAllCapacity.Text = "Original Capacity"
    Case 2
    cboAllCapacity.Text = "Increase 5% Capacity"
    Case 3
    cboAllCapacity.Text = "Increase 10% Capacity"
    Case 4
    cboAllCapacity.Text = "Increase 20% Capacity"
    Case 5
    cboAllCapacity.Text = "Increase 35% Capacity"
    Case 6
    cboAllCapacity.Text = "Increase 50% Capacity"
    Case 7
    cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "SP3"))
 mdl.Data("Capacity") = txbSP3.Text

 'S31
 Set mdl = mdls(mdls.Find(smFindTag, "S31"))    'find module
 Select Case mdl.Data("Capacity")
    Case 1
    cboAllCapacity.Text = "Original Capacity"
    Case 2
    cboAllCapacity.Text = "Increase 5% Capacity"
    Case 3
    cboAllCapacity.Text = "Increase 10% Capacity"
    Case 4
    cboAllCapacity.Text = "Increase 20% Capacity"
    Case 5
    cboAllCapacity.Text = "Increase 35% Capacity"
    Case 6
    cboAllCapacity.Text = "Increase 50% Capacity"
    Case 7
    cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S31"))
 mdl.Data("Capacity") = txbS31.Text
```

```
'S32
 Set mdl = mdls(mdls.Find(smFindTag, "S32"))     'find module
 Select Case mdl.Data("Capacity")
   Case 1
   cboAllCapacity.Text = "Original Capacity"
   Case 2
   cboAllCapacity.Text = "Increase 5% Capacity"
   Case 3
   cboAllCapacity.Text = "Increase 10% Capacity"
   Case 4
   cboAllCapacity.Text = "Increase 20% Capacity"
   Case 5
   cboAllCapacity.Text = "Increase 35% Capacity"
   Case 6
   cboAllCapacity.Text = "Increase 50% Capacity"
   Case 7
   cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S32"))
 mdl.Data("Capacity") = txbS32.Text

 'S33
 Set mdl = mdls(mdls.Find(smFindTag, "S33"))     'find module
 Select Case mdl.Data("Capacity")
   Case 1
   cboAllCapacity.Text = "Original Capacity"
   Case 2
   cboAllCapacity.Text = "Increase 5% Capacity"
   Case 3
   cboAllCapacity.Text = "Increase 10% Capacity"
   Case 4
   cboAllCapacity.Text = "Increase 20% Capacity"
   Case 5
   cboAllCapacity.Text = "Increase 35% Capacity"
   Case 6
   cboAllCapacity.Text = "Increase 50% Capacity"
   Case 7
   cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "S33"))
 mdl.Data("Capacity") = txbS33.Text
```

```
'VSP1
Set mdl = mdls(mdls.Find(smFindTag, "VSP1"))     'find module
Select Case mdl.Data("Capacity")
    Case 1
    cboAllCapacity.Text = "Original Capacity"
    Case 2
    cboAllCapacity.Text = "Increase 5% Capacity"
    Case 3
    cboAllCapacity.Text = "Increase 10% Capacity"
    Case 4
    cboAllCapacity.Text = "Increase 20% Capacity"
    Case 5
    cboAllCapacity.Text = "Increase 35% Capacity"
    Case 6
    cboAllCapacity.Text = "Increase 50% Capacity"
    Case 7
    cboAllCapacity.Text = "Increase 75% Capacity"
End Select

Set mdl = mdls(mdls.Find(smFindTag, "VSP1"))
mdl.Data("Capacity") = txbVSP1.Text

'VSP41
Set mdl = mdls(mdls.Find(smFindTag, "VSP41"))     'find module
Select Case mdl.Data("Capacity")
    Case 1
    cboAllCapacity.Text = "Original Capacity"
    Case 2
    cboAllCapacity.Text = "Increase 5% Capacity"
    Case 3
    cboAllCapacity.Text = "Increase 10% Capacity"
    Case 4
    cboAllCapacity.Text = "Increase 20% Capacity"
    Case 5
    cboAllCapacity.Text = "Increase 35% Capacity"
    Case 6
    cboAllCapacity.Text = "Increase 50% Capacity"
    Case 7
    cboAllCapacity.Text = "Increase 75% Capacity"
End Select

Set mdl = mdls(mdls.Find(smFindTag, "VSP41"))
mdl.Data("Capacity") = txbVSP41.Text
```

```
'VSP42
 Set mdl = mdls(mdls.Find(smFindTag, "VSP42"))    'find module
 Select Case mdl.Data("Capacity")
   Case 1
   cboAllCapacity.Text = "Original Capacity"
   Case 2
   cboAllCapacity.Text = "Increase 5% Capacity"
   Case 3
   cboAllCapacity.Text = "Increase 10% Capacity"
   Case 4
   cboAllCapacity.Text = "Increase 20% Capacity"
   Case 5
   cboAllCapacity.Text = "Increase 35% Capacity"
   Case 6
   cboAllCapacity.Text = "Increase 50% Capacity"
   Case 7
   cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "VSP42"))
 mdl.Data("Capacity") = txbVSP42.Text

 'VSP43
 Set mdl = mdls(mdls.Find(smFindTag, "VSP43"))    'find module
 Select Case mdl.Data("Capacity")
   Case 1
   cboAllCapacity.Text = "Original Capacity"
   Case 2
   cboAllCapacity.Text = "Increase 5% Capacity"
   Case 3
   cboAllCapacity.Text = "Increase 10% Capacity"
   Case 4
   cboAllCapacity.Text = "Increase 20% Capacity"
   Case 5
   cboAllCapacity.Text = "Increase 35% Capacity"
   Case 6
   cboAllCapacity.Text = "Increase 50% Capacity"
   Case 7
   cboAllCapacity.Text = "Increase 75% Capacity"
 End Select

 Set mdl = mdls(mdls.Find(smFindTag, "VSP43"))
 mdl.Data("Capacity") = txbVSP43.Text
```

```
ErrorOccurred:
'Initialise to defaults
   cboAllCapacity.Text = "Original Capacity"
         txbSP1.Text = "50000"
         txbS11.Text = "50000"
         txbS12.Text = "50000"
         txbS13.Text = "50000"

         txbSP2.Text = "100000"
         txbS21.Text = "100000"
         txbS22.Text = "100000"
         txbS23.Text = "100000"

         txbSP3.Text = "100000"
         txbS31.Text = "100000"
         txbS32.Text = "100000"
         txbS33.Text = "100000"

         txbVSP1.Text = "50000"
         txbVSP41.Text = "50000"
         txbVSP42.Text = "50000"
         txbVSP43.Text = "50000"

   Err.Clear
End Sub
```

Coding for Configuring Separator Utilisation Interface Form

```
Private Sub cboSPUtilisation_Change()

    Select Case cboSPUtilisation.Text
        '55% SP Utilisation
        Case "55% Utilisation"
        txbOneLine.Text = "5433.62"
        txbTwoLines.Text = "5433.62"
        txbThreeLines.Text = "5433.62"
        txbFourLines.Text = "5433.62"

        '57% SP Utilisation
        Case "57% Utilisation"
        txbOneLine.Text = "7244.82"
        txbTwoLines.Text = "7244.82"
        txbThreeLines.Text = "7244.82"
        txbFourLines.Text = "7244.82"

        '61% SP Utilisation
        Case "61% Utilisation"
        txbOneLine.Text = "10867.24"
        txbTwoLines.Text = "10867.24"
        txbThreeLines.Text = "10867.24"
        txbFourLines.Text = "10867.24"

        '72% SP Utilisation
        Case "72% Utilisation"
        txbOneLine.Text = "21734.47"
        txbTwoLines.Text = "21734.47"
        txbThreeLines.Text = "21734.47"
        txbFourLines.Text = "21734.47"

    End Select
End Sub

Private Sub cmdCancel3_Click()

    Simulate = False

    Unload frmConfigSPUtilisation

    Set m = ThisDocument.Model
    Set s = m.SIMAN

    'End the model run.
    m.End
End Sub
```

```
Private Sub cmdNext_Click()


'Apply Capacity Data or Set Method for Property Construction
Dim mdl As Arena.module
Dim mdls As Arena.modules
Set mdls = ActiveModel.modules

  'Stage1RegRate
  Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))     'find Stage 1 Input
Rate Module
  Select Case cboSPUtilisation.Text
    Case "55% Utilisation"
      mdl.Data("Initial Value(1)") = 1
      mdl.Data("Initial Value(2)") = 2
      mdl.Data("Initial Value(3)") = 3
      mdl.Data("Initial Value(4)") = 4
    Case "57% Utilisation"
      mdl.Data("Initial Value(1)") = 5
      mdl.Data("Initial Value(2)") = 6
      mdl.Data("Initial Value(3)") = 7
      mdl.Data("Initial Value(4)") = 8
    Case "61% Utilisation"
      mdl.Data("Initial Value(1)") = 9
      mdl.Data("Initial Value(2)") = 10
      mdl.Data("Initial Value(3)") = 11
      mdl.Data("Initial Value(4)") = 12
    Case "72% Utilisation"
      mdl.Data("Initial Value(1)") = 13
      mdl.Data("Initial Value(2)") = 14
      mdl.Data("Initial Value(3)") = 15
      mdl.Data("Initial Value(4)") = 16
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))
    mdl.Data("Initial Value(1)") = txbOneLine.Text
    mdl.Data("Initial Value(2)") = txbTwoLines.Text
    mdl.Data("Initial Value(3)") = txbThreeLines.Text
    mdl.Data("Initial Value(4)") = txbFourLines.Text

  Simulate = False


  'Unload the form
  Unload frmConfigSPUtilisation

  'Show Production Line Selection Form
  frmConfigSPCap.Show vbModal
End Sub
```

```
Private Sub UserForm_Initialize()
On Error GoTo ErrorOccurred

'Setup Combo-box Lists
cboSPUtilisation.AddItem "55% Utilisation"
cboSPUtilisation.AddItem "57% Utilisation"
cboSPUtilisation.AddItem "61% Utilisation"
cboSPUtilisation.AddItem "72% Utilisation"

'Apply Capacity Data
Dim mdl As Arena.module
Dim mdls As Arena.modules
Set mdls = ActiveModel.modules

  'Initial Value (1)
  Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))    'find Stage1
Regulator Rate variable
  Select Case mdl.Data("Initial Value(1)")
    Case 1
    cboSPUtilisation.Text = "55% Utilisation"
    Case 5
    cboSPUtilisation.Text = "57% Utilisation"
    Case 9
    cboSPUtilisation.Text = "61% Utilisation"
    Case 13
    cboSPUtilisation.Text = "72% Utilisation"
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))
  mdl.Data("Initial Value(1)") = txbOneLine.Text


  'Initial Value (2)
  Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))    'find Stage1
Regulator Rate variable
  Select Case mdl.Data("Initial Value(2)")
    Case 2
    cboSPUtilisation.Text = "55% Utilisation"
    Case 6
    cboSPUtilisation.Text = "57% Utilisation"
    Case 10
    cboSPUtilisation.Text = "61% Utilisation"
    Case 14
    cboSPUtilisation.Text = "72% Utilisation"
  End Select

  Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))
  mdl.Data("Initial Value(2)") = txbTwoLines.Text

  'Initial Value (3)
```

```
   Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))    'find Stage1
Regulator Rate variable
   Select Case mdl.Data("Initial Value(3)")
      Case 3
      cboSPUtilisation.Text = "55% Utilisation"
      Case 7
      cboSPUtilisation.Text = "57% Utilisation"
      Case 11
      cboSPUtilisation.Text = "61% Utilisation"
      Case 15
      cboSPUtilisation.Text = "72% Utilisation"
   End Select

   Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))
   mdl.Data("Initial Value(3)") = txbThreeLines.Text

   'Initial Value (4)
   Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))    'find Stage1
Regulator Rate variable
   Select Case mdl.Data("Initial Value(4)")
      Case 4
      cboSPUtilisation.Text = "55% Utilisation"
      Case 8
      cboSPUtilisation.Text = "57% Utilisation"
      Case 12
      cboSPUtilisation.Text = "61% Utilisation"
      Case 16
      cboSPUtilisation.Text = "72% Utilisation"
   End Select

   Set mdl = mdls(mdls.Find(smFindTag, "Stage1RegRate"))
   mdl.Data("Initial Value(4)") = txbFourLines.Text


ErrorOccurred:
'Initialise to defaults
   cboSPUtilisation.Text = "61% Utilisation"
        '61% SP Utilisation
        txbOneLine.Text = "10867.24"
        txbTwoLines.Text = "10867.24"
        txbThreeLines.Text = "10867.24"
        txbFourLines.Text = "10867.24"

   Err.Clear
End Sub
```

Coding for Configuring Water Contents Interface Form

```
Private Sub cboWaterAmount_Enter()

  'Call Search for Directory
  SearchDir = ProjectFileDir + "*.XLS"
  XLSFile = Dir(SearchDir)
  cboWaterAmount.Clear
  cboWaterAmount.value = ""
  cboWaterAmount.Text = ""

  'Configure  XLSFile
  If XLSFile = "" Then
    X = MsgBox("Cannot Find Input File. Simulation End")
    Simulate = False
  Else
    cboWaterAmount.AddItem XLSFile
    Do While XLSFile <> ""
      XLSFile = Dir()
      If XLSFile <> "" Then
        cboWaterAmount.AddItem XLSFile
      End If
    Loop
  End If
End Sub

Private Sub cmdSimulate_Click()
Set m = ThisDocument.Model
Set s = m.SIMAN

''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
  'Configuration for Water Amount
  InputFile = cboWaterAmount.value
  If InputFile <> "" Then
    XLInput = ProjectFileDir + InputFile
  End If

''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
  'Run Model / Start Simulation
  Simulate = True

  'Close down Configuration Form
  Unload frmWaterConfiguration

''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
End Sub
```

```
Private Sub cmdCancel_Click()

    'Do not start Simulation
    Simulate = False

    'Close down Configuration Form
    Unload frmWaterConfiguration

    Set m = ThisDocument.Model
    Set s = m.SIMAN

    'End the model run.
    m.End

    'The m.QuiteMode is used to turn off all messages (i.e. Summary Report)
    m.QuietMode = True

End Sub
```

Coding for Configuring Water Contents Interface Form

```
Private Sub cmdCancel_Click()
    'Do not start Simulation
    Simulate = False

    'Close down Configuration Form
    Unload frmProdLine

    Set m = ThisDocument.Model
    Set s = m.SIMAN

    'End the model run.
    m.End


End Sub

Private Sub cmdNext_Click()
Dim m As Arena.Model
Dim s As Arena.SIMAN
Set m = ThisDocument.Model
Set s = m.SIMAN

''''''Configure the Production Line Selection''''''''''''''''''''''''''''''
Dim Activate1, Activate2, Activate3, Activate4 As module
Dim mdlLine1 As Integer
Dim mdlLine2 As Integer
Dim mdlLine3 As Integer
Dim mdlLine4 As Integer

    'set module Line1 equal to Create module Crude Oil 1
    mdlLine1 = m.modules.Find(smFindTag, "CrudeOil1")
    mdlLine2 = m.modules.Find(smFindTag, "CrudeOil2")
    mdlLine3 = m.modules.Find(smFindTag, "CrudeOil3")
    mdlLine4 = m.modules.Find(smFindTag, "CrudeOil4")

    'set Activate1 as item of Create module Crude Oil 1
    Set Activate1 = m.modules.Item(mdlLine1)
    Set Activate2 = m.modules.Item(mdlLine2)
    Set Activate3 = m.modules.Item(mdlLine3)
    Set Activate4 = m.modules.Item(mdlLine4)

    'Replace the value from textbox to Item Max Batches
    Activate1.Data("Max Batches") = frmProdLine.txbLine1.value
    Activate2.Data("Max Batches") = frmProdLine.txbLine2.value
    Activate3.Data("Max Batches") = frmProdLine.txbLine3.value
    Activate4.Data("Max Batches") = frmProdLine.txbLine4.value
```

```
 'Replace the value from textbox to Item Max Batches
  If frmProdLine.txbLine1.value = "" Then
    Activate1.Data("Max Batches") = 0
  End If

  If frmProdLine.txbLine2.value = "" Then
    Activate2.Data("Max Batches") = 0
  End If

  If frmProdLine.txbLine3.value = "" Then
    Activate3.Data("Max Batches") = 0
  End If

  If frmProdLine.txbLine4.value = "" Then
    Activate4.Data("Max Batches") = 0
  End If

  'Update the data
  Activate1.UpdateShapes
  Activate2.UpdateShapes
  Activate3.UpdateShapes
  Activate4.UpdateShapes

  Simulate = False

  'Hide frmProductionLine
  Unload frmProdLine

  'Show Production Line Selection Form
  'frmConfigSPCap.Show vbModal

End Sub
```

Coding for Arena Modules

```
'Select Input File
Public XLInput As String

'Project File Current Directory(Path)
Public ProjectFileDir As String

'Set to start or stop simulation
Public Simulate As Boolean

Option Explicit
Option Compare Binary
'Declare windows API function for checking whether a character is alphanumeric (A-
Z,0-9)
Private Declare Function IsCharAlphaNumericA Lib "user32" (ByVal byChar As
Byte) As Long
'Declare windows API function for checking whether a character is alphabetic (A-Z)
Private Declare Function IsCharAlphaA Lib "user32" (ByVal bytChar As Byte) As
Long
Private Function dhIsCharAlpha(strText As String) As Boolean
'Is the first character of strText an alphabetic character (A-Z)?
   dhIsCharAlpha = CBool(IsCharAlphaA(Asc(strText)))
End Function
Private Function dhIsCharAlphaNumeric(strText As String) As Boolean
'Is the first character of strText an alphanumeric character (A-Z,0-9)?
   dhIsCharAlphaNumeric = CBool(IsCharAlphaNumericA(Asc(strText)))
End Function
Private Function CheckSymbolName(ByVal str As String) As Boolean
'Checks whether str is a valid symbol name

'Declarations
Dim intI As Integer
Dim strChar As String * 1
Dim blnAlphaNumeric As Boolean
Dim blnAlphabetic As Boolean

'Guilty until proven innocent :(
CheckSymbolName = False

If Len(str) > 0 Then
   'Get first character in string
   strChar = Mid$(str, 1, 1)
   If (StrComp(strChar, "e") = 0) Then
   'If the first character is the letter "e" then
   'we have a valid symbol name
      CheckSymbolName = True
      Exit Function
   End If
```

```
 For intI = 1 To Len(str)
     'Get next character in str
     strChar = Mid$(str, intI, 1)
     'Is the character alphanumeric (A-Z,0-9)?
     blnAlphaNumeric = dhIsCharAlphaNumeric(strChar)
     If (strChar Like "[@_%?#. ]") Or (blnAlphaNumeric) Then
     'The character is valid special character or alphanumeric so still OK
       'Is the character alphabetic (A-Z)?
       blnAlphabetic = dhIsCharAlpha(strChar)
       If (strChar Like "[@_%?#]") Or (blnAlphabetic And StrComp(strChar, "e")
<> 0) Then
       'We will have a valid symbol name assuming no invalid characters exist
         CheckSymbolName = True
       End If
     Else
     'The character is an invalid character so return false
       CheckSymbolName = False
       Exit Function
     End If
   Next
Else
'If str is NULL then return true
  CheckSymbolName = True
End If

End Function
Private Function CheckInteger(ByVal str As String, Optional vntmin As Variant) As
Boolean
'Validates whether str is an integer greater than or equal to vntmin

'Declarations
Dim intI As Integer
Dim lngI As Long
Dim strChar As String * 1
Dim blnNumeric As Boolean
```

```
'Innocent until proven guilty :)
CheckInteger = True

If Len(str) > 0 Then
   For intI = 1 To Len(str)
   'Get next character in string
      strChar = Mid$(str, intI, 1)
      'Is the character numeric?
      blnNumeric = (strChar Like "[0-9]")
      If Not blnNumeric Then
      'str can't be an integer so return false
         CheckInteger = False
         Exit Function
      End If
   Next

   If Not IsMissing(vntmin) Then
   'If vntmin is defined then also check minimum condition
      lngI = CLng(str)
      If lngI < vntmin Then CheckInteger = False
   End If
End If

End Function
Private Function CheckReal(ByVal str As String, Optional vntmin As Variant) As
Boolean
'Validates whether str is a real greater than or equal to vntmin

'Declarations
Dim dblval As Double

On Error GoTo NotReal
'Innocent until proven guilty :)
CheckReal = True

If Len(str) > 0 Then
   'Try to store str in a double. If an error occurs then we will go to NotReal label and
return
   'false
   dblval = CDbl(str)

   If Not IsMissing(vntmin) Then
   'If vntmin is defined then also check minimum condition
      If dblval < vntmin Then CheckReal = False
   End If
```

```
    'Also, make sure a comma character wasn't in the string (which wouldn't error when
storing
    'in a double.
    If (InStr(1, str, ",", vbBinaryCompare) <> 0) Then
        CheckReal = False
    End If

End If

Exit Function

NotReal:
  CheckReal = False
End Function
Private Function CheckExpression(ByVal str As String) As Boolean
'Validates whether str is a valid expression

'Declarations
Dim intI As Integer
Dim strChar As String * 1
Dim intOpen As Integer
Dim intClose As Integer
Dim blnAlphaNumeric As Boolean

For intI = 1 To Len(str)
    'Get next character in str
    strChar = Mid$(str, intI, 1)
    'Is the character alphanumeric (A-Z,0-9)?
    blnAlphaNumeric = dhIsCharAlphaNumeric(strChar)
    If Not ((strChar Like "[@_%?#. ,()*+=/<>]") Or (blnAlphaNumeric) Or (strChar =
"-")) Then
    'The character is an invalid character so return false
        CheckExpression = False
        Exit Function
    End If
Next
```

```
'Now check parentheses
For intI = 1 To Len(str)
  'Get next character in string
  strChar = Mid$(str, intI, 1)
  'Count number of open paren
  If strChar = "(" Then intOpen = intOpen + 1
  'Count number of close paren
  If strChar = ")" Then intClose = intClose + 1
Next
'Number of open paren must equal number of close paren to be valid expression
CheckExpression = (intOpen = intClose)

End Function

Public Function CheckDataType(ByVal strValue As String, ByVal strDataType As
String, Optional vntmin As Variant) As Boolean
'Checks whether strValue is a valid strDataType.

'Check the data type
strDataType = StrConv(strDataType, vbLowerCase)
Select Case strDataType
   Case "symbol name"
      CheckDataType = CheckSymbolName(strValue)
   Case "integer"
      CheckDataType = CheckInteger(strValue, vntmin)
   Case "real"
      CheckDataType = CheckReal(strValue, vntmin)
   Case "expression"
      CheckDataType = CheckExpression(strValue)
End Select

End Function
```

Appendix D

Picture of Manifold, Separators and Tanks

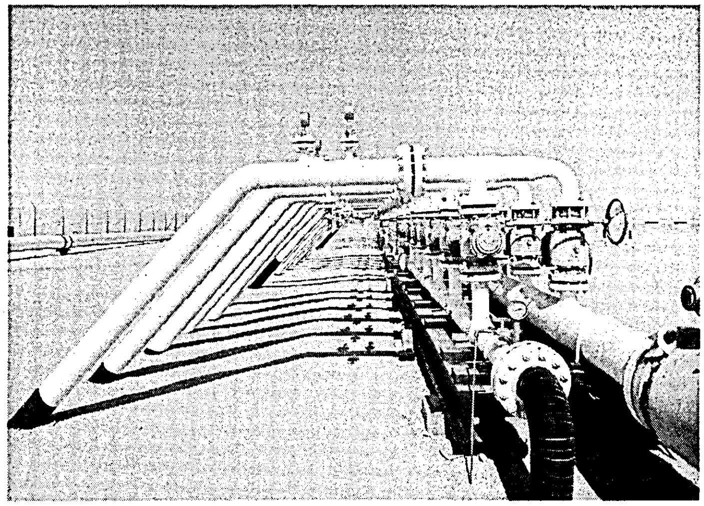


Figure 1 Manifold (Source:BASF Group, (2008), [online], Last accessed on 13 April 2007 at http://www.corporate.basf.com/basfcorp/img/presse/foto-dvd/fotos/gross/03_Kundenbranchen/05_Energie/15_Verteilerkreuz_einer_Oelleitung.jpg)

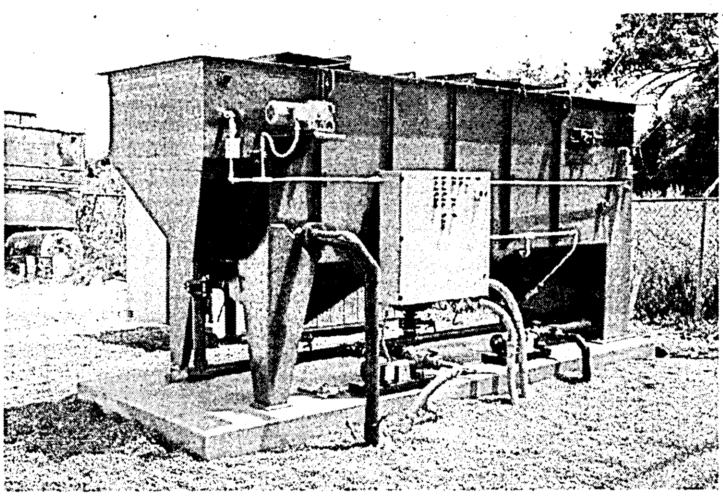


Figure 2 API Oil - Water Separator (Source: PAN America Environmental, (2004), "API Series Steel API Separators 1-600 GPM", [online], last accessed on 13 April 2007 at http://www.oil-water-separator.net/oil-water-separator.html

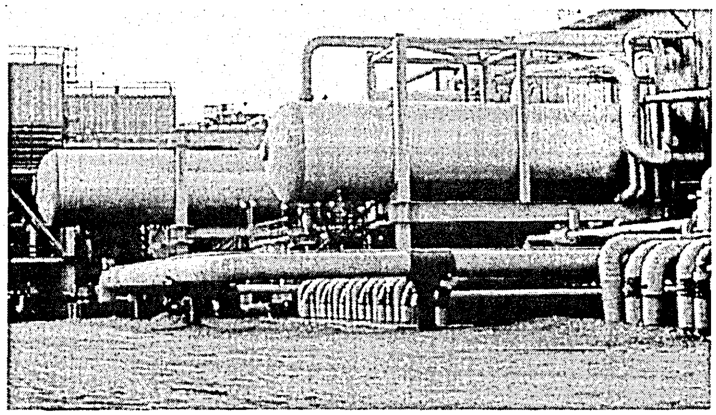


Figure 3 Horizontal Separator. (Source: NATCO, (2008), "Horizontal Dual Flow Separator", [online], last accessed on 13 April 2007 at http://www.natcogroup.com/ViewFullPicture.asp?ImageID=214)

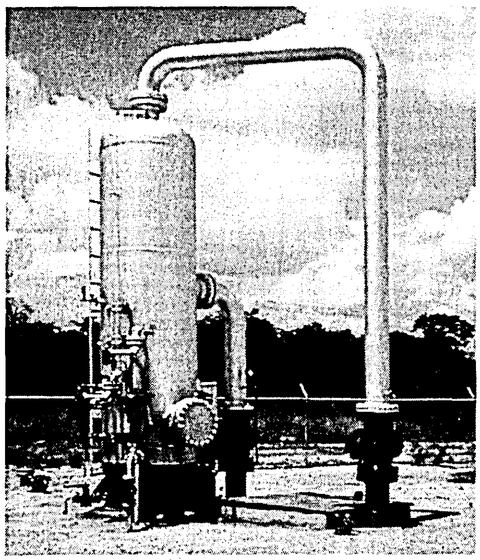


Figure 4 Vertical Separator (Source: NATCO, (2008), "Vertical Upflow Separator", [online], last accessed on 13 April 2007 at http://www.natcogroup.com/ViewFullPicture.asp?ImageID=216)

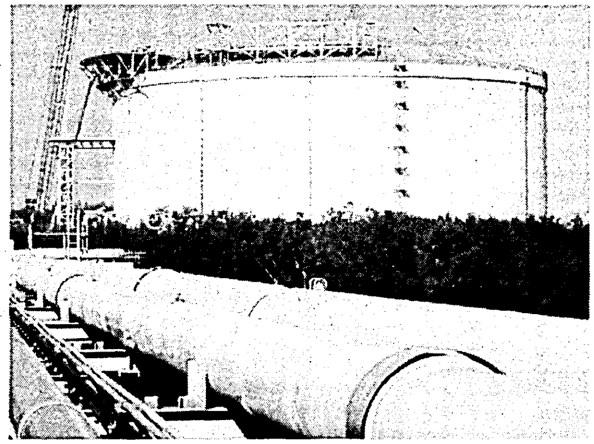


Figure 5 Oil Storage Tank (Source: Chart Industries, (2007), "UNITED STATES SECURITIES AND EXCHANGE COMMISSION", Chart Industries, Inc, 30 March 2007, [online]. Last accessed on 20 April 2007 at http://google.brand.edgar-online.com/EFX_dll/EDGARpro.dll?FetchFilingHTML1?SessionID=uTNOCgomAhBBei2&ID=5071623