AN INTEGRATED DECISION SUPPORT SYSTEM BASED ON SIMULATION AND MATHEMATICAL PROGRAMMING OF PETROLEUM TRANSPORTATION LOGISTICS

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Thesis submitted in fulfilment of the requirements for the award of the degree of Doctor of Philosophy in Technology Management.

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedicated To

My

Parents;

Beloved wife;

Lovely children: Abdullah and Mustafa;

Brothers and sisters

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In the Name of Allah, the Most Gracious, the Most Merciful. Praise be to Allah, the Lord of the Worlds; peace and blessings of Allah be upon the noblest of the Prophets and Messengers, our Prophet Mohammed and upon his family, companions and who follows him until the last day. I am truly and deeply indebted to so many people that there is no way to acknowledge them all or even any of them properly. So, I offer my sincerest apologies to anyone I ungratefully omitted from explicit mention.

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ABSTRACT

Discrete Event simulation (DES), mathematical programming (MP) and analysis of variance (ANOVA) are among the popular tools in operational research (OR) used in dynamic industry like petroleum industry. The integration of these methods even becomes more significant to managerial application in the industry. The objective of this thesis is to present an integrated decision support system by which a decision maker should be able to choose the optimal number of tanks, tank size and truck arrival rate to maximize average total profit and minimize the total transportation cost for an oil refinery terminal operations. The petroleum transportation management system (PTMS) is developed as a DSS using a discrete-event simulation program with ARENA software, mathematical linear programming (LP) with I-Log software and analysis of variance (ANOVA) with SPSS software, and these models are combined in complex program developed using visual basic software (VB).

The simulation model represents the logistics operations from oil arriving to the refinery terminal to the supply points. The model process used as a decision support tool to help in evaluating and improving the comprehensive oil terminal operations. And also understanding and assessing of the different steps in a simulation process.

An optimization model was formulated with the objective to minimize the total transportation cost. In the model formulation, hard constraints were considered and the linear programming (LP) technique was used. Result obtained suggests the use of certain types of trucks can reduce the operation costs, if compared to that of the current situation. The reduction of costs is due to the reduction of travelling trips as based on the problem constraints. Overall, output of this study has given positive impacts on the transportation operations. The effect of the changes can help the management of the transportation company to make efficient decisions.

Multifactor ANOVA is used to determine whether different levels of the three-factors and their interactions significantly impact the oil refinery terminal's profit. ANOVA is also used to determine the flow rate of oil into the tanks station; tank and truck fill rate and a cost and revenue structure.

The final step is to expand the model to cover the whole models (DES, LP and ANOVA) and create the integrated user interface. To sum up the combination of these techniques which allows evaluating the actual feasibility of supply planning considering all operations restrictions and variability of the supply logistics and the total transportation cost. In another words, a DSS have been developed to support a decision maker, who is planning to build a new facility or expand an existing oil refinery terminal, should be able to choose the optimal value for all important factors. The PTMS is able to predict with 99% confidence a set of factor levels that yields the highest average total profit.

ABSTRAK

Kaedah simulasi diskrit (DES), pengaturcaraan matematik (MP) dan analisis varian (ANOVA) merupakan antara metodologi yang popular dalam bidang penyelidikan operasi (OR) yang sering digunakan dalam industri dinamik seperti industri petroleum. Integrasi ketiga-tiga kaedah ini pula menjadi lebih signifikan kepada aplikasi pengurusan bagi industri tersebut. Tujuan kajian tesis ini ialah untuk membangunkan suatu sistem yang dapat membantu dalam pembuatan keputusan yang bersepadu. Pembuat keputusan dapat memilih jumlah optimum tangki, saiz tangki dan tahap ketibaan lori bagi menetukan keuntungan maksimum serta dapat meminimumkan kos pengangkutan terminal. Sistem Pengangkutan Pengurusan Petroleum (PTMS) ini dibangunkan dengan menggunakan kaedah simulasi diskrit yang menggunakan perisian ARENA, pengaturcaraan linear matematik (LP) menggunakan perisian I-Log dan analisis varians (ANOVA) dengan menggunakan perisian SPSS. Sistem ini kemudiannya digabungkan dalam sebuah program yang dibangunkan pula dengan menggunakan perisian visual basic (VB).

Model simulasi yang dibina bagi operasi logistik ini bermula dari petroleum tiba di terminal hingga ke pusat penyerahan atau depot. Model ini digunakan sebagai kaedah membantu membuat keputusan bagi menilai dan meningkatkan tahap kecekapan operasi terminal secara menyeluruh. Ia juga meningkat kefahaman dan menilai langkah-langkah yang berbeza dalam proses membina model simulasi.

Model pengoptimuman pula dibina untuk tujuan meminimumkan jumlah kos pengangkutan. Dalam pembentukan model tersebut, kendala keras diambil kira dan teknik pengaturcaraan liner (LP) digunakan. Keputusan yang diperolehi menunjukkan bahawa penggunaan jenis lori tertentu dapat mengurangkan kos operasi. Pengurangan kos ini diperolehi kerana pengurangan dalam perjalanan seperti yang ditetapkan oleh kendala masalah. Secara keseluruhan, dapatan kajian ini telah memberikan kesan positif terhadap operasi pengangkutan. Kesan perubahan ini telah dapat membantu pihak pengurusan syarikat pengangkutan ini bagi membuat keputusan yang cekap.

Kaedah multifaktor ANOVA pula telah digunakan bagi menentukan sama ada tahap yang perbezaan oleh tiga faktor, interaksi secara signifikan dapat memberi kesan terhadap keuntungan terminal. Kaedah ini juga diguna bagi menentukan tahap kecekapan mengepam minyak ke dalam tangki tangki stesen, dan tahap kecekapan mengisi minyak ke lori dan kos serta struktur penerimaan.

Langkah terakhir membangunkan model ialah dengan mengintegrasi model keseluruhan (DES, LP dan ANOVA) dan membina antara-muka pengguna. Untuk jumlah kombinasi teknik-teknik ini membolehkan menilai kelayakan sebenar perancangan bekalan mempertimbangkan semua sekatan operasi dan variabilitas dari bekalan logistik dan pengangkutan total cost. Dengan lain perkataan, sistem pendukung keputusan (PTMS) telah dibangunkan untuk membantu pembuat keputusan yang merancang samada untuk membina kemudahan baru atau memperluaskan terminal kilang minyak yang sedia ada. Sistem ini sepatutnya boleh memilih nilai yang optimum untuk semua faktor yang penting. PTMS mampu meramal dengan keyakinan 99% satu set level faktor yang menghasilkan jumlah keuntungan.

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NOMENCLATURES

List of Symbols

m^3	Cubic Meters
FindJ	Module Conducts A Search over An Index from the Start of the Range to the End of the Range to Find the Value of A Global Variable *J*that Satisfies the Search Condition
$	United State Dollar
$K	Thousands of United State Dollar
CD's	Compact Discs
Truck_TBA	Average Time between Arrival of A Trucks at the Oil Terminal
Oil_TBA	Average Time between Arrival of A Batch of Oil at the Tank Terminal
Tank fill time	Time Required to Fill 20 m^3 of Oil Into A Tank
Truck fill time	Time Required to Fill 40 $m^3$of Oil into A Tank
Batch size	Oil Entities Arrive at the Storage Tanks in 3 Batch Sizes; Small, Medium and Large
Truck capacity	The Maximum Volume of Oil that A Truck Can Hold
storage tanks capacity	The Maximum Volume of Oil that the Storage Tanks Can Hold - Derived as A Product of Number of Tanks and Tank Size
Oil WIP	Counter to Track the Total Oil Entities Within the Storage Tanks System
Truck WIP	Counter to Track the Total Truck Entities Within the Tanks Station System
Queue capacity	The Number of Truck(S) the Central Truck Queue Can Hold
Truck cost per minute	The Cost Per Minute Charge for A Truck
Cost per truck per trip	The Cost Charged Per Truck Per Trip
Lease cost	The Cost Per Minute Incurred to Maintain the Oil Refinery Facility
Regular oil CM	The Contribution Margin Derived from the Sale of 1 $M^3$of Regular Oil

Discount oil CM	The Contribution Margin Derived From the Sale of 1 $M^3$of Discount Oil
Tank size	The Maximum Volume (1,000 m^3) of Oil that A Tank Can Hold
Number of tanks	Number Of Storage Tanks in the Refinery Terminal
CM	Contribution Margin
Warm up Period	The Time Required for the System to Reach Study State.
P	Total Profit
R	Total Contribution Margin
C	Total Cost
H_{0A} / H_{0B} / H_{oc}	Null Hypothesis
FCFS	First-Come-First-Serve
$\overline{X}$	The Sample Average
α	Significance Level
N	Number of Replications
γ	The Relative Error
$\acute{\gamma}$	The Adjusted Relative Error
t	Student T Statistics
Std Dev	Standard Deviation
SS	Type III Sum of Squares
MS	Mean Square
df	Degrees of Freedom
I	*Number of Tanks* Factor Levels

J	*Truck_TBA* Factor Levels
K	*Tank Size* Factor Levels
L_{ijk}	the number of observations made with factor *truck_TBA* at level *i*
L	Total Number of Observations per Design Point
m	Number of Levels Being Compared
v	Degrees of Freedom
h	number of observations arranged to obtain each of the averages being compared
X_{ij}	The Integer Number of Trips Taken to Transport An Oil from Origin *i* to Destination *j*
C_{ij}	Distance Between Refinery *i* and Destination *j*
$D_j^{\,p}$	Processing Capacity of Oil at Destination*j*
$S_i^{\,p}$	Total m^3 Supply for Oil at Refinery *i*
$V^{\,p}$	m^3 Capacity of Vehicle Transporting Oil

LIST OF ABBREVIATIONS

OR	Operational Research
LP	Linear Programming
DES	Discrete Event Simulation
VB	Visual Basic
ANOVA	Analysis of Variance
SPSS	Statistical Package for the Social Sciences
MA	Mathematical Programming
ITMS	Integrated Transportation Management System
I-LOG	Mathematical Modelling Package
VBA	Visual Basic Application
ARENA	Simulation Modelling Package
PTMS	Petroleum Transportation Management System
OPL	Optimization Programming Language
IDE	Integrated Development Environment
API_S	Application programming interfaces
QP	Quadratic Programming
DSS	Decision Support System
GUI	Graphic User Interface
OOP	Object Oriented Programming
O-D	Origin-To-Destination
LTL	Less-Than-Truckload
TL	Truck Load
MILP	Mixed-Integer Linear Programming
CPLEX	It Is Named for the Simplex Method and the C Programming Language
IRP	Inventory Routing Problem
GRASP	Greedy Randomized Adaptive Search Procedure
PR	Path Re-linking

ISO	International Organization for Standardization
IMO	International Maritime Organization
ITS	Intelligent Transportation Systems
SD	System Dynamics
DEDS	Discrete-Event Dynamic Systems
SC	Supply Chain
GSC	Global Supply Chain
SCM	Supply Chain Management
MDP	Markov Decision Process
VRP	Vehicle Routing Problem
ABC	Activity-Based Costing
LRP_S	Location-Routing Problems
TSP	Travelling Salesman Problem
IP	Integer Programming
DMC^2	Dynamic Transportation Model With Multiple Criteria And Multiple Constraint Levels
MC^2	Multiple Criteria And Multiple Constraints
DC	Distribution Centers
DP	Dynamic Programming
GA	Genetic Algorithm
FCTP	Fixed-Charged Transportation Problem
MIP	Mixed Integer Programming
IP	Integer Programming
ADRT	AL-Dura Refinery Terminal
CRN	Common Random Numbers
DOE	Design of Experiment
MSE	Mean Squared Error
mts	Minutes
$Z(\mathbf{X})$	Objective Function
X_i	The Column Vector of Decision Variables

C	The Row Vector
SOMO	State Oil Marketing Organization
DBMS	Database Management System
MBMS	Model-Base Management System
DGMS	Dialog Generation and Management System
I/O	Input/ Output
OLE	Object Linking And Embedding

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The oil industry is vertically integrated activities dealing with a very large range of activities extending from oil and gas exploration to refining and distribution. Figure 1.1 in general illustrates a high level view of oil industry supply chain. The oil can be bought either from abroad using tanker or produced in the company productions site. The crude oil needs to be transported to the refinery in order to be transformed into fuels or others products. Mainly two means of oil transportation are used either oil trucks or pipelines. At the refinery the crude oil is refine to produce different kind of oil products such as benzene, kerosene, diesel etc. Then these products are transported to the depots using trucks. At the depots, these products are stored in the big tanks. Depots are acted as an inventory and the depot is usually located close to the consumer. From the depot the products will be delivered to the secondary depots or industries premises.

The major oil companies usually setup their refineries close to the depots, where the depots become a distribution center to the customers. The decision of setting up a depot is basically based on the location of the customers. According to Hill (2003), the strategy of facility location is normally forecasted by the sales and marketing departments. The company then will look into its capability and capacity to fulfill the costumer requirement. The company will devise its aggregate strategic planning.

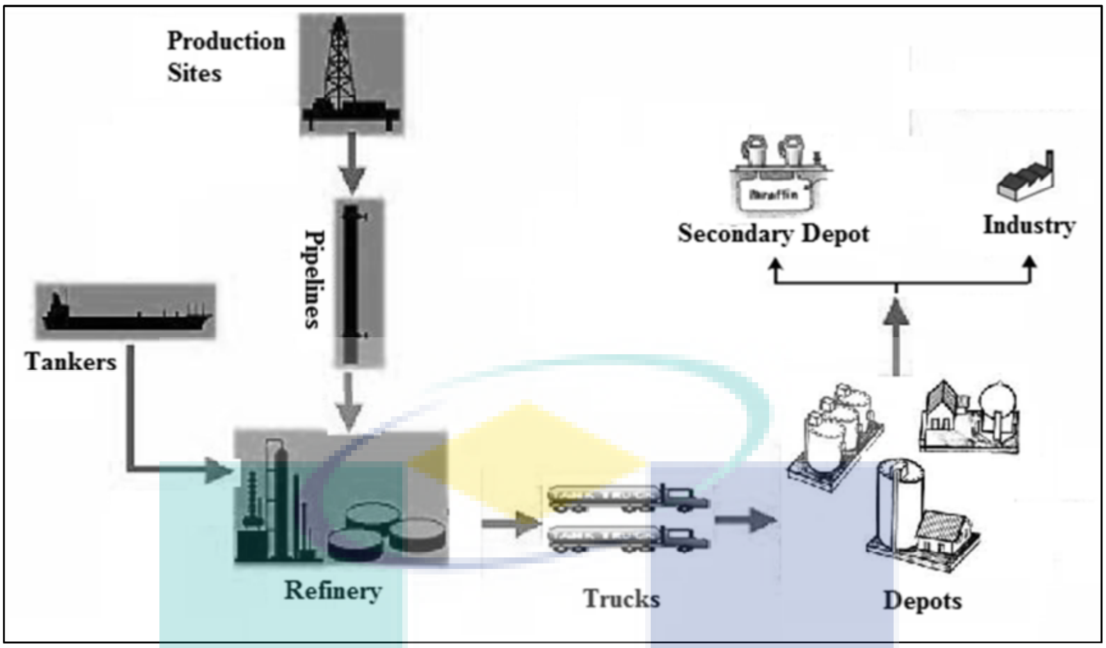


Figure 1.1: Oil industry supply chain

Without a reliable forecast by the sales & operation department, the company will lose a lot of profit due to mismatch between the long-range business strategy and operational activities Hill (2003). Therefore reliable methods are needed to do a good decision.

Oil industry is among the popular application of operational research (OR) methods. Linear programming (LP) is a good example of OR method in this industry. The example of LP used is in the optimization of oil extraction, refining, blending, saving in tanks and distribution. The objective function of LP is normally to evaluate the maximum profit that could be obtained by setting constraints and limitation. The constraints in this industry are normally refining configuration, costs of crude production, transport and utilities. Many works have been done using optimization techniques in oil and gas industry (Neiro and Pinto, 2003, Lasschuit and Thijssen, 2004, Aires et al., 2004).

Other application of OR methods that become very important in industrial system is discrete event simulation (DES). DES is used to represent a portion of the real world, such that experiments in the simulation model can predict what will happen in the reality (Hollocks, 1992). Basically, a simulation model provides support to the decision-making process, allowing the reduction of risks and costs involved in a process (Vieira, 2004). It is used to reproduce the material flux in a supply chain or in manufacturing processes. It takes into account not only the limited recourses but also the stochastic characteristics of the events.

In general the aim of LP model is to identify best values for a set of decision variables to find the optimal operation point. But they are unable to deal with the uncertainties of many real world problems. DES is used to assess operations considering these uncertainties and the complexity of the process (April et al., 2004).

Many studies have focus on LP and DES (Azadivar, 1999; Fu et al., 2000; April et al., 2003; Cheng and Duran, 2003). Most of the studies using the method singularly without integrating or combining the methods. Bush et al. (2003) also suggested the utilization of a combination of the two techniques (optimization and simulation) but there are no integration between these two techniques. The goal of their study was to obtain the more feasible solution for oil transportation in any oil refinery terminal. The solution of the study only considers aspects related to time and sequencing of operations.

Oil is among the cheapest energy sources, (Campbell and Laherre, 1998). The demand of the oil is always increasing between 2000 and 2010 see Figure 1.2. As a result of an increasingly competitive market, petroleum companies must find ways to organize their activities regarding their revenue (economic outcome). An important feature in this context involves transportation operations, usually considered one of the major bottlenecks in the oil supply chain. While delays imply loss of time and lack of the resources distribution, deliveries ahead of the deadlines may cause excess of inventories. Therefore, every oil company must pursue efficient transportation schedules within their operational planning.

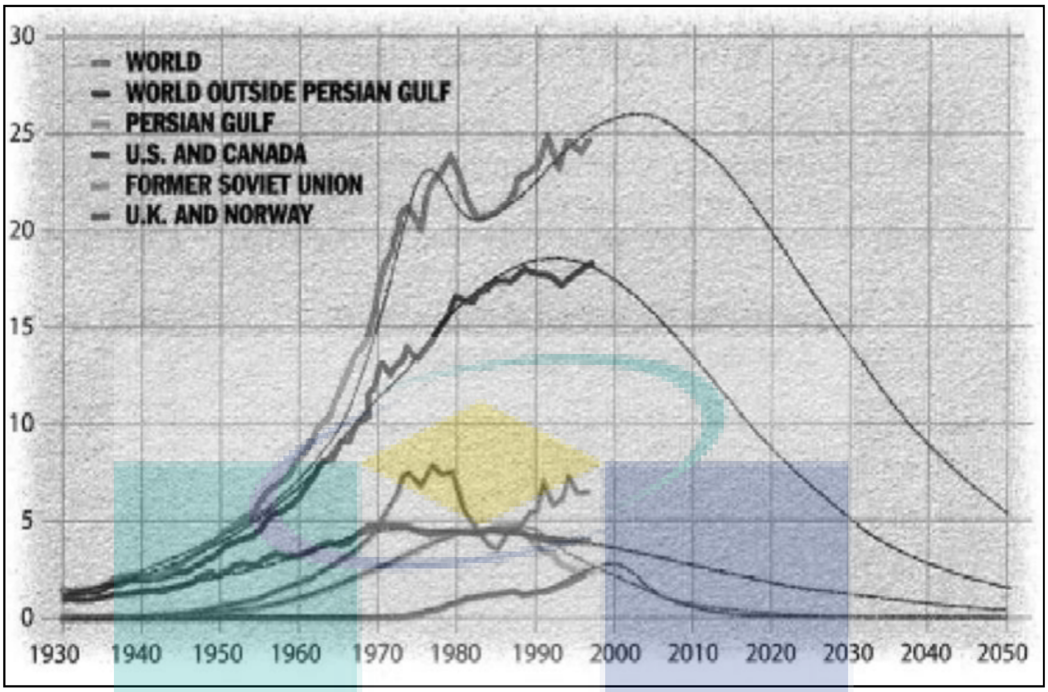


Figure 1.2: Annual oil production (billions of barrels)

Facility location decisions are crucial because inefficient location for production will result in excess cost being incurred throughout the lifetime of the facility. Thus, refineries that process a few hundred thousand cubic meters (m^3) of oil every day, if not rightly located can cause serious impact on the continual prosperity of the oil industry. The tanks locations ever been studied and will determine that they are appropriately located to facilitate the efficient and economical flow of oil from the nearest tanks, *Tank Capacity*? Where should all the tanks be located in relation to one another, so that total transportation cost is minimized? If the oil production transportation is considered together, then the problem is where to optimally maximize the total profit, also minimized the total transportation cost. All oil derivatives must be sent from the refineries to the depots. At present, the purchase of oil delivery assignment is done by refineries. The refinery will decide on its delivery to the depot. The depots can purchase oils from any refinery because oil price is not a factor to them. However to the refinery it is an important factor because the transportation cost is covered by the refinery. The nearer the depot to the refinery the better it will be because transportation cost can be reduced substantially.

The contribution factors that cause the crisis to the consumers can be summarized:

i. The deterioration of transport efficiency aggravates the crisis which leads to the Non-delivery of gasoline and other products to depots quickly and easily and without delay.
ii. Lack of storage in inventory, it is certainly a lack of storage will lead to fuel crisis.
iii. Weak organization with insufficient managerial role (opportunistic role for some workers at distribution points).

1.2 PROBLEM STATEMENT

Oil companies have abundant resources of petroleum products in storage tanks, retail gasoline stations, home heating oil tanks, lubricant storage at automotive service facilities, propane tanks in all sorts of applications, and oil company terminals across the world. To manage these resources professionally, it is important to have the products at the right place, in the right quantity, at the right time and at the right price.

Overfilling a tank or having too many tanks filled with oil is potentially a misuse of precious resources. If tank managers manage supplies too tightly, they risk running low at times of crucial need, resulting in unscheduled fillings that are often expensive.

In summary, there are important points to clarify the problem statement as follows;

i. Considering the economic crises and the Increasing of petroleum demand. This study will focus on decreasing the total transportation cost and also increasing the profit.
ii. Weakly manage or a misuse of precious resources such as over filling a tank or having too many tanks filled with oil.
iii. As a result of an increasingly competitive market, petroleum companies must find ways to organize their activities regarding their revenue (economic outcome).

1.3 OBJECTIVES OF THE STUDY

The primary goal of this research is to develop a decision support system (DSS) to investigate and improve the combined the profit and transportation cost in a representative oil refinery storage and supply problems. The expectation that through applying the proposed simulation model for an oil refinery designers and activity operators may benefit from the simulation output information and from which the knowledge and skill level of designers and operators may be elevated. The major objectives of this research are summarized as follows:

i. To develop a generic simulation model (a hybrid and integrated decision support system) of oil refinery operations to support a decision maker, who is planning to build a new facility or expand an existing terminal, should be able to choose the optimal *Number of Tanks*, *Tank Capacity* and *Truck Arrival Rate* to maximize the profit of the oil terminal operations.
ii. To develop a generic mathematical model to minimize the total transportation cost of oil between the refinery and the depots. Also to find the optimal total transport distance for the oil from selected refinery and sent to several depots. This in actual will optimally assign refineries-to-depots, which refinery will send its oil to which depots and by how much
iii. To evaluate the real feasibility of the results of optimization process through the experimentation of the statistical analysis and using new technique.
iv. To develop a user interface and implementing software applications based on the simulation model and visual basic (VB). Also to investigate the behavior and improve the performance of the developing system.

1.4 METHODS OF ANALYSIS

The methodology for this thesis is four-fold.

i. Discrete event simulation: integrate the simulation model. Simulation input/output will be presented, and then this study will provide some details about the simulation model and controller design. Finally, results of the simulation including graphic animation and simulation reports and analyzing statistical results will be demonstrated.

ii. Analysis of Variance (ANOVA): Statistical Package for the Social Sciences (SPSS) is an excellent choice for data science analysis; it has been extended to a wide-range of business, scientific and information modeling applications.

iii. Mathematical programming (MA): Develop a LP model by using mathematical programming to find the optimal total cost through minimizing the total distance.

iv. Integrated transportation management system (ITMS): build a user interface windows by using visual basic application programming (VBA) with ARENA software. Petroleum transportation management system (PTMS) will provide and help the decision maker to choose the optimal values for the input parameters to find the total profit. Based on that, this study will construct a decision support system to assist decision makers to study and improve the combined profit and transportation cost.

1.5 DEFINITION OF TERMS

This section will first provide definitions of all fundamental concepts in the methodologies, as follows;

Discrete Event Simulation (DES): Simulation is a very powerful decision-making tool to solve and analyze a wide range of practical problems. There are two types of simulation models, i.e. continuous and discrete-event. A continuous model describes the rates at which the values of attributes change with respect to time, while in a discrete-event model; the variables are of discrete quantities representing states of entities in the system, as in an oil refinery system.

In any simulation study, the process begins with problem identification and problem formulation. Then after the objective of study have been set, then the model building and data collection can be performed concurrently. Then the coding, verification and validation can take placed. After that the experimental design and model experimentation will be conducted until a significant obtained. This approach is not necessarily unique but in general they have common elements (Centeno, 1996).

Figure 1.3 presents the general simulation process as proposed by many simulation modelers (Gogg, 1993; Nordgren, 1995).

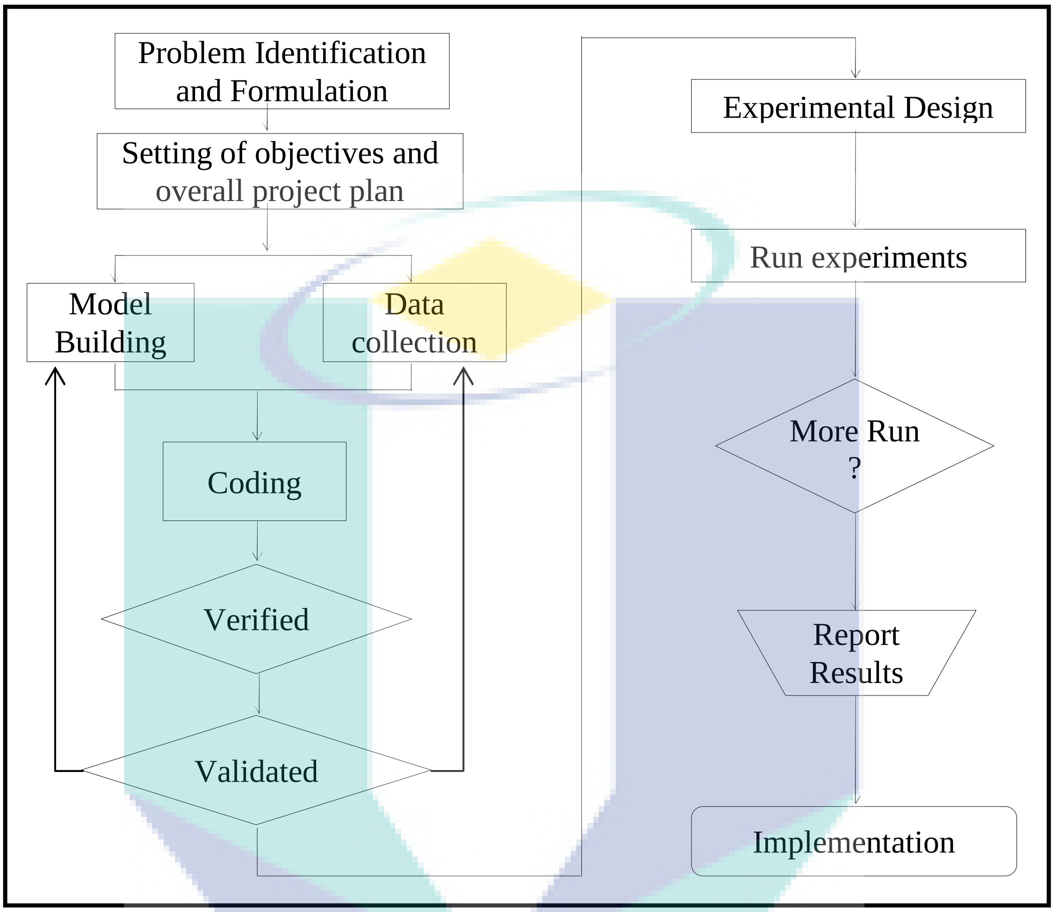


Figure 1.3: The simulation modeling process

Statistical analysis: in this study, a rigorous statistical analysis is performed using analysis of variance (ANOVA). Describe the hypothesis and the experimentation (multifactor analysis of variance and tukey) procedures required to determine the best combination of factor levels. Also to understand which factors and their interactions are significant. The aim is to find that combination that optimizes the system. A multifactor single analysis of variance (ANOVA) will perform on all the factors to identify the best combination of factor levels that will yield the highest profit. Tukey's method of identifying significantly different means will use to test whether or not there does exist a combination of the factors for which the mean profit is statistically higher than other factor-level mix for the factor under study.

Mathematical Programming: A model is a representation of reality. It can be thought of as an entity, which captures the essence of but without the presence of reality. A mathematical model is an equation, inequality, or system of equations or inequalities, which represents certain aspects of the physical system modeled. The mathematical expression, which describes the behavior of the measure of effectiveness, is called the objective function. Objective functions are written in mathematical expression containing variables, the value of which is to be determined. If the objective function is to describe the behavior of the measure of effectiveness, it must capture the relationship between that measure and those variables that cause it to vary. Therefore in the objective function the decision maker needs to answer the question, “what values should these variables have so that the mathematical expression has the greatest possible value (maximization) or the least possible numerical value (minimization). System variables are either decision variables or parameters.

Integrated Transportation Management System (ITMS): The study is also including with developing an integrated decision support system (DSS). The system is named Integrated Transportation Management System (ITMS). It will provide the decision maker with a decision support system based on simulation; this study was developed a self-contained framework that integrates the simulation model and mathematical model such that the decision maker is able to manipulate the system model through the Graphic user interface (GUI). The simulation architecture also consists of a simple interface so that users can specify initial conditions and parameters and obtain results during the simulation or at the end of the simulation. The simulation model that represents the behavior of the real system is constructed in Arena, together with I-Log and built-in Visual Basic for Application (VBA) modules.

1.6 SIGNIFICACE OF THE STUDY

The study is focusing on developing three models namely discrete event simulation (DES), mathematical linear programming (LP) and analysis of variance (ANOVA). Based on these models, a DSS is built. It is concerned with developing a decision support system (DSS) to assist decision makers with the study, design and control of the simulation/transportation system in oil refinery operations. The integration of discrete event simulation and mathematical programming of the combined simulation and transportation system provides the foundation for the decision support system. The simulation model and the mathematical model are formulated in a consistent and interactive manner so that the insight and results obtained from either one can be utilized to validate and improve the other.

Many previous studies focusing on a single method only. This kind of approve is inadequate because of the limitation of the method. For example, simulation model is only capable of solving a limited problem which mathematical programming may be more suitable. Simulation cannot obtain the optimum solution but through mathematical programming the optimum can be to obtain. This is the first academic study to apply the discrete events simulation (DES), mathematical linear programming (LP) and ANOVA, to find the optimal profit and in the same time the optimal transportation distance for oil refinery operations. By using two different software's (ARENA, I-Log).

With the use of the proposed simulation frameworks, a construction operation simulation can be designed, created, or modified for the given simulation objectives. Decision maker may control the simulation through a friendly and easy-to-use interface. Simulation progress is rendered in real time, and simulation output results are also available instantly. Through visualized simulations, users have the opportunity to practice or experience construction operations in a more efficient, less expensive, and safer way before or during implementing them in real construction worksites

The linear programming optimization model of oil refinery transportation is a means to investigate the minimum transportation cost. That is, it provides the means to assess the inputs, outputs, and input-output transformation within the context of the firm's objectives. As such, the study provides the foundation of the economic analysis in both policy and managerial decision-making.

The important benefits of this study can summarize as follows;

i. Develop a hybrid model to investigate and improve the combined simulation and transportation system in a representative oil refinery operations.
ii. Decision making with the use of simulation frameworks, application modifications or expansions can be easily made. Consequently, various solutions to a target study problem can be compared side by side, and by which optimal decision can be easily achieved.
iii. Performance evaluating through this simulation application, planners can evaluate operation performance from various viewpoints.
iv. Physical skill learning operation simulations may be designed based on demonstrations of experienced or skilled operators. Less experienced operators may learn physical skills through observation or operation of the simulation.
v. Verbal description comprehending a series of operational descriptions or processes may be better understood through visualized simulation animations.
vi. Petroleum transportation management system (PTMS), help a decision maker to manage precious resources efficiently, by have the products: At the right place, in the right quantity, at the right time and at the right price.
vii. The study will propose new integration decision support control system for oil transportation to get the total cost and maximum profit.

1.7 SCOPE OF THE STUDY

The scope of the proposed ITMS should be described from three aspects: the simulation modeling, the LP and ANOVA.

The simulation can be applied in a very wide range of studies, no single simulation system could possibly include all models for simulating all subjects of study. The inclusion of selected simulation models depends on the simulation objectives and study problems. To adequately represent the actual situation of construction operations, this research will focus on models that can accurately represent the oil refinery terminal logistics operations. These included models will form a supply and transportation models for calculating the total profit and total transportation cost of an oil terminal.

Therefore, the scope of the simulation modeling in this research is defined by the developed functions of the oil refinery operations.

The integer mathematical programming models were developed to solve the oil transportation problems for any oil company. These products from the refineries were sent to their respective destinations. The transportation problems were solved to get the refineries-to-depots optimal assignments using distance minimization as the objective function. Truck capacities are homogeneous for each product, and refineries and depots are located at identical locations.

Multifactor ANOVA is used to determine whether different levels of the three-factors and there, interactions significantly impact the oil refinery terminal's profit. Tukey's procedure is used to determine which combination of levels of *Number of Tanks*, *Tank Capacity* and *Truck Arrival Rate* will result in highest average total profit per week. Given an oil flow rate into the tanks station, tank and truck fill rate and a cost and revenue structure. The objective of this study is consists of determining a supply, transport and distribution logistics schedule to maximize the profit and minimize the total transportation cost.

1.8 OUTLINE OF THE THESIS

This thesis consists of seven chapters. Each chapter of this dissertation covers the component topic that forms the structure of this research. The chapters are organized according to the role that each component plays in the structure as shown in Figure 1.4. Each chapter begins with an introductory section followed by supporting descriptions, methodologies, or model development.

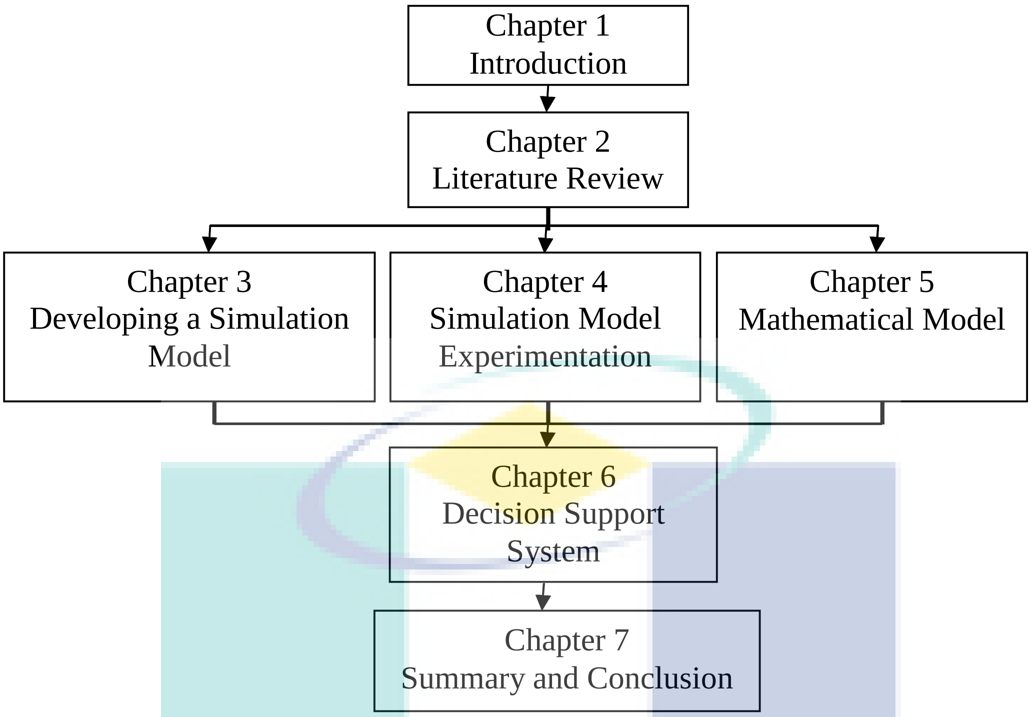


Figure 1.4: Organization of the dissertation

The current chapter gives an introduction to this research, including statement of the problem, objectives of the study, proposed methodology, significant of the study, organization of the dissertation and conclusion.

Chapter 2 presents a literature review on study of transportation, simulation, location, mathematical programming, oil refinery operations and highlights the need for further study.

Chapter 3 begins with the discussion on simulation modeling concepts. This chapter focuses on the development and the derivation of the simulation model. The first addresses the concept and importance of using software ARENA. Together with the model Data collection, variable definitions, scope of the study are defined. The simulation procedure and model is explained, and simulation verification and validation steps are discussed.

Chapter 4 describe the hypothesis and the experimentation, multifactor analysis of variance (ANOVA) and multifactor analysis of variance and Tukey's procedures required to determine the best combination of factor levels. Also to understand which factors and their interactions are significant.

Chapter 5 develop a generic mathematical programming model using I-Log Software to find the best refinery-to-depots assignments. Also to find the minimum possible transportation distance, so the total cost will be a minimum.

Chapter 6 integrated framework will design to provide the decision maker with a decision support system based on simulation and VB. Develop a self-contained framework that integrates the simulation model and controller such that the decision maker is able to manipulate the system model through the controller. Build a user interface window by using object oriented programming (OOP) to help the decision maker test the factors and see the result from the outputs.

The final chapter, Chapter 7 concludes the thesis by summarizing the study's findings and by identifying recommendations for future embellishments.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Transport or transportation can be defined as the movement of a person or a load from its origin to its destination by a sequence of at least two transportation modes (Crainic and Kim, 2007). The Latin term “trans” means across and portare, to carry. In the prehistoric days people has been moving by riding on animal backs, and then arks that move on water surfaces by rowing or by the wind. Later with the invention of wheels, carts are made to move people and goods that are pulled by animals. In the 1700’s when the steam engine came, water transport improved dramatically. This invention of the steamboat was the first time that a mechanical machine was used in transportation. This sets the starting trend of active inventions of the steam powered locomotive and the internal combustion engine of the century thereafter. Air transport takes off when the first engine airplane was invented in the beginning of the twentieth century (Ibrahim , 2008).

The broad field of transportation can loosely be divided into infrastructure, vehicles and operations. Infrastructure usually includes roads, railways, airways, pipelines, and so on, which come under the domain name of networks. It can also include the nodes, such as airports, railway stations, seaports, etc. Vehicles move on the networks. Automobiles, trains, airplanes are some of the examples. Operations deal with control of the system, such as traffic signals, railroad switches and air traffic control.

Transportation is about physical movement. Each movement of people or goods has a starting and ending point and follows a route. The size of such movements is represented as origin-to-destination (O-D) movements, of flows, between pairs of places. While, the supply of transportation facilities and services is represented by nodes and links that reflects the physical connectivity between these places. Together, these links and nodes constitute a transportation network over which people and goods travel (Murphy et al., 2008).

The means, or modes, of transportation are mostly motor-powered vehicles, trains, airplanes, ships and pipelines. Motor carriers are the most important user of the highway system and the most flexible mode of transportation. It offers door-to-door service, local pickup and delivery, and small as well as large shipment hauling. Motor carriers can also offer very specialized services from refrigerated, to livestock, to automobile hauling. Motor carriers are most often classified as less-than-truckload (LTL) carriers or truck load (TL) carriers. Trucks that carry LTL freight have space for and plan to carry shipments of many other customers simultaneously. Unlike TL carriers, LTL carriers operate through a system of terminals, and from each terminal trucks go out to customers, delivering and picking up shipments. These shipments are then taken to a terminal, where they are loaded aboard line-haul trucks, which are driven to a terminal near the freight destination. The goods are unloaded from the line-haul carrier, move through the terminal, and are loaded aboard a small truck for local delivery. TL traffic may involve only one customer, it is also possible that large shipments from several customers can be consolidated into a truckload shipment. Further, TL shipments tend to move directly from the shippers location to the consignee’s location. Motor carriers can also be classified based on the types of goods they haul. General freight carry the majority of goods shipped and include common carriers, while specialized carriers transport liquid petroleum, household goods, agricultural commodities, building materials, and other specialized items (Peterson, 2010).

Rail Carriers are for transporting heavy or bulky goods over a long distance. The advantage of this mode is mostly in being cheap. But the disadvantage is that it is slow. Although freight railroads have the potential to transport different kind of products, they have tended to focus on lower-value, high-volume shipments of bulk-type commodities such as coal, cement, chemicals, farm products, and nonmetallic minerals. In terms of volume that can be carried at any one time, rail is superior to air and motor. Boxcars (used to carry general freight), hopper cars (used to carry coal and minerals), and tank cars (used for liquid or liquefiable products) have usable carrying capacities of approximately 100 tons a piece.

Water Carriers are very useful but slow and inflexible. Goods that use this mode must be heavy, bulky and low value like coal, timber, grain and sand. The most obvious disadvantage being it is limited to areas accessible by water. Inland waterways are significant in the U.S. and E.U. but faced with some challenges; water levels drop too low in time of drought, flood, irregular transit time due to upstream movement against the prevailing current, and inflexibility in the sense that it can operate where there are appropriate waterways. Development and use of supertankers have added a dimension that did not previously exist. The use of container ships that stack up thousands of containers and crosses oceans enhances trades between countries and flourishes trades among major ports (Murphy et al., 2008).

Pipelines are unique mode of transportation because it is the only one without the need for vehicle operators, an important consideration given that vehicle operators are paid and compensated, sometimes engage in work stoppages (e.g., strike) and can be the cause of accidents. On the other hand pipelines tend to be the slowest form of transportation; the lack of vehicles means that the relevant products need to be forced through the pipeline. From capability perspective, pipelines are quite limited in the sense that products must be liquid, liquefiable, or gaseous in nature. Indeed, pipelines are probably best known for transporting petroleum products and natural gas, either crude or refined (Ibrahim , 2008).

2.2 PETROLEUM TRANSPORTATION

The refining and marketing sector of the oil industry is a high-volume, low-margin business in which efficiency is essential to survival. Nowhere is that efficiency more evident than in the transportation of crude oil. Even with the physical system, transportation is a major cost for the oil industry, and a great deal of effort is directed to improving the competitive position of individual companies through investment, trades, and supply realignment (National Petroleum Council, 1989). The oil industry made a fundamental strategic decision early in its history not to own all its tonnage needs, which opened up doors for independent businessmen to provide a shipping service to the oil companies. If oil companies had made the decision to own all their tonnage needs, there would be no tanker owners. However, making the decision that permits tanker owners to exist benefited parties, lowering transportation cost for the oil companies and providing sources of business for the tanker owners. The primary functions of an integrated oil company are to explore for oil, develop oil fields, refine crude oil, and market refined products. Transportation, be it by pipelines, ships, barges, railroad cars, or tank trucks, is not a source of profit, but a cost of doing business (Tusiani, 1996).

Most domestic crude oil is refined in the same region in which it is produced; however, there is a two-step process intra- publishes oil supply and demand data movement/transportation from wellhead to refineries:

i. Through gathering, which is the collection of crude oil from individual properties in small-diameter pipelines or by truck for input into a large-diameter pipeline.
ii. Through mainline or trunk line transportation, which is the movement of the "gathered" oil to refineries.

Crude oil imports are transported by pipelines, but the bulk of imported crude oil is delivered by foreign-flag tank ships. The relatively long transit times for many foreign crude oils are a significant factor in crude oil supply planning and dynamics, since it may take up to 45 days in transit after loading; therefore, for a refiner, long transit time means reduced supply flexibility and higher levels of inventory and inventory cost. In a highly volatile market, long transit times also increase the risk of adverse market changes between purchase and delivery. However, to offset these disadvantages, some producers resort to selling long-haul crude oil from transshipping terminals and price it based on the market at or near the delivery date (National Petroleum Council, 1989).

As we well know, oil is an important strategic material to most countries in the world. Unfortunately the production and the consumption of oil are usually geographically separated, that is, an oil extraction plant is usually far away from the final consumption market of its oil products. For example, most oil fields are located in Middle East, West Africa, South America and Russia; but the main consumption markets lie in East Asia, Europe and North America, the average distance from an extraction plant to a consumption market reaches several thousand sea miles. At the same time, the transportation of oil is expensive; its cost may reach several dollars per barrel. Thus, effective transportation planning is a very important issue in the trade of oil. In real life, oil can be transported in multiple transportation modes including pipeline, tanker, train and trucks, in which pipeline and trucks are more suitable for a long distance transportation of oil. As the distance between an oil refinery and its corresponding import depot is usually quite long, trucks are considered as one major transportation modes of oil in this study. Because of the existence of multiple transportation modes, a heterogeneous fleet of trucks and various logistics costs, the effective transportation planning of oil has a high complexity and is a challenge issue in petroleum logistics (Shen et al. 2011).

This thesis studies an oil transportation planning problem, in which oil is transported from a supply center (refineries) to a set of customer harbors (depots) with dynamic demands and limited inventory and shortage capacities. Oil is transported by an oil distributor using a heterogeneous fleet of trucks. The trucks may be owned by the oil distributor itself or rented from a third party at the supply center with rental costs. The inventory cost of holding oil at each depot is taken in account. Because of the limited transportation capacity or the need for the reduction of transportation costs, backlogging of part of a depot’s demand is allowed but with a penalty (backlogging cost). The problem is to determine for each period over a given time horizon the *Number of Trucks* of each type to be rented/returned and the *Number of Tanks* and *Tank Capacity* to maximize the total profit and minimize the total logistics cost including the transportation costs.

In the literature, several papers have studied various oil transportation problems. Brown, Graves, and Ronen (1987) considered a tanker routing and scheduling problem for transporting oil between an export terminal and an import terminal, where a single type of tankers with a single compartment was used for each type of oil in each delivery with a single loading and unloading port. The problem was formulated and solved as an elastic set partitioning problem which determines the least expensive schedule for each cargo. Similar to the problem studied by Brown et al. (1987) and motivated by an oil transportation problem of Kuwait Petroleum Corporation (KPC), Sherali, Al-Yakoob.

Mohammed, and Hassan (1999) studied a tanker routing and scheduling problem with delivery time-windows, in which a supply port, several demand ports and multiple types of ships with various compartments were considered. The problem was modeled as a complex mixed-integer linear programming (MILP) and solved with CPLEX for small instances. Later on, an aggregate model that retains the principal features of the MILP model was formulated and solved for practical size instances by using a specialized rolling horizon heuristic. To minimize the environmental pollution caused by oil spill incidents and to optimize the logistic costs of the maritime transportation of oil products.

Iakovou (2001) presented a multi-objective network flow model to describe a problem of maritime transportation of oil products between multiple origins and destination locations, with the aim to minimize transportation costs and expected risk costs (due to oil spills). The model was then decomposed into two sub problems, one is a risk problem and the other is a transportation problem. An interactive solution methodology was proposed to solve the sub problems.

MirHassani and Ghorbanalizadeh (2008) present an integer programming approach to oil derivative transportation scheduling. The system reported is composed of an oil refinery, one multi-branch multi-product pipeline connected to several depots and also local consumer markets which receive large amounts of refinery products.

Feng et al. (2008) transformed a point-to-point oil transportation problem with a homogeneous fleet of tankers into a single item lot sizing problem, and developed a polynomial dynamic programming algorithm to solve it. Sandy Thomas (2009) reported on the results from an extensive computer model developed over the last decade to simulate and compare the societal benefits of deploying various alternative transportation options including hybrid electric vehicles and plug-in hybrids fueled by gasoline, diesel fuel, natural gas, and ethanol, and all-electric vehicles powered by either batteries or fuel cells.

Jeong et al. (2010) developed four transportation scenarios for a maritime transportation by considering the type of transportation casks and transport means in order to suggest safe and economical transportation logistics for the spent fuels in Korea. And, this study estimated and compared the transportation risks for these four transportation scenarios.

As the problem studied in this thesis PTMS can be regarded as an integrated DSS. Chien et al. (1989) studied a multiple period's inventory routing problem (IRP) and solved the problem using a comprehensive decomposition scheme in a rolling horizon framework, in which a vehicle routing problem is repeatedly solved over a 2-week moving period. A general introduction of IRP is provided by Campbell et al. (1998). For more work on multiple period IRPs, readers can refer to Campbell et al. (2001) and Kleywegt et al. (2002). Campbell and Savelsbergh (2004) proposed a decomposition approach to a multiple periods IRP in a rolling-horizon framework as well, where a delivery schedule is first created by solving an integer programming model and a set of delivery routes is then constructed based on the schedule.

Compared with the problems studied in the literature and cited above, the problem is more complex. Firstly, the trucks dispatching decisions are made over multiple periods with the constraints of satisfying depots' demands and the upper and lower bounds of the inventory level at each depot, the problem is thus a multiple-period inventory routing problem rather than a single period delivery planning problem; and as oil can be transported from a refinery directly to a set of demand depots, it is in fact a supply and transportation problem with multiple transshipment between refineries and depots. Secondly, our problem involves supply and transportation modes, which include *Trucks Arrival Rate*, *Number of Tanks* and *Tank Capacity*, using multiple types of methods (DES , ANOVA and LP), which include general DSS of oil industry.

Few papers studied a similar or the same oil transportation problem. Navani et al. (2002) developed a computer method and apparatus for petroleum trading and logistics. The software includes various computer tools for the different individual (crude and product traders. planner/analysts, brokers, schedulers, vessel owner/brokers, terminal operators, pipeline operators and cash brokers, etc.) involved in crude oil trading. A type of software, a network of computers, a method for evaluating, collaborating and negotiating crude oil, intermediates and refined products trading and logistics.

Guy and Nelson (2004) studied a refinery, scheduling of incoming crude oil using a genetic algorithm. Within the generic algorithm, firstly a period T which the crude oil shipment schedule is formed. A generation of chromosomes is randomly generated, with each chromosome in the generation representing a possible solution.

Cheng and Duran (2004) studied a crude oil transportation and inventory problem with multiple transportation modes including tankers and pipelines but all tankers have identical capacity, they developed a decision support system which integrates discrete event system simulation and stochastic optimal control to evaluate and improve decisions for the problem.

Shen et al. (2009) proposed a mixed-integer programming model to the same problem studied in this paper and developed a meta heuristic method, Greedy Randomized Adaptive Search Procedure enhanced by Path Re-linking method (GRASP/PR), to find a near-optimal solution of the problem. The method performs well for randomly generated instances of small-to-medium sizes. However, for large instances, the computation time of the method for finding a high quality solution becomes quite long. Thus, a more efficient approach is needed to solve large instances of the problem.

Gary et al. (2010) developed a method and apparatus for transporting bulk material optimally. The decisions are made based on transportation routes and schedules for the transportation vehicles, allocation of cargo to be transported to one or more demand location by the transportation vehicles, nomination of cargo pickup by the transportation locations, and vehicles assignments for each of the transportation, vehicles. The optimization may be performed to maximize the total net margin of transportation or minimize the cost of transporting.

Song et al. (2010) developed a system for optimizing bilk product allocation, transportation and blending. A computer loaded with the system when activated will execute and causes the computer to optimize for maximum net profit margin, the product allocation, transportation routing, and transportation vehicle\route scheduling. Optionally, blending bulk of products and deliver to a demanded location by using heterogeneous fleet of transportation vehicles over a pre-defined period of time.

Shen et al (2011) studied the inventory routing problem in crude oil transportation, in which crude oil is transported from a supply center to multiple customer harbors to satisfy their demands over multiple periods. A heterogeneous fleet of tankers consisting of tankers owned by a distributor and tankers rented from a third party, a pipeline, and multiple types of routes are considered; both inventory level and shortage level at each customer harbor are limited. Formulating the problem as a mixed integer programming problem only and developed a Lagrangian relaxation approach to find a near optimal solution of the problem.

2.3 TRUCKS IN THE COMMERCIAL TRANSPORT

A truck is a motor vehicle for transporting goods. Unlike automobiles, which usually have a uni-body construction, most trucks (with exception of the car-like minivan) are built around a strong frame called chassis. They come in all sizes, from the automobile-sized pickup truck to towering off-road mining trucks or heavy highway semi-trailers.

Trucks can be classified according to size. Light trucks are car-sized and are used by individuals and commercial entities alike. They comprised pickup trucks, full-size vans, tow-trucks, mini-vans and sports utility vehicles. Medium trucks are bigger than light but smaller than heavy trucks. They are mostly used for local delivery and public services such as dump trucks and garbage trucks. Examples of this type are delivery truck, multi-stop truck, platform truck, flatbed truck and bottler. Heavy trucks are the largest trucks allowed on the road. They are mostly used for long-haul purposes, often in semi-trailer configuration. They comprise dump truck, garbage truck, concrete transport truck, semi-trailer, refrigerator truck and tank truck (Ibrahim, 2008).

2.3.1 Tank Trucks

A tank truck or tanker lorry is a motor vehicle designed to carry liquefied loads, dry bulk cargo or gases on roads. The largest such vehicles are similar to railroad tank cars, which are also designed to carry liquefied loads. Many variants exist due to the wide variety of liquids that can be transported. Tank trucks tend to be large; they may be insulated or non-insulated; pressurized or non-pressurized; and designed for single or multiple loads.

Tank trucks are referenced by their size or volume capacity. Large trucks typically have capacities ranging from 15,000 liters to 40,000 liters. A tank truck is distinguished by its shape, and is usually a cylindrical tank upon the vehicle lying horizontally. Some other less visible distinctions among tank trucks are their intended use: compliance with human food regulations, refrigeration capability, acid resistance, pressurization capability, and others. Large tank trucks are used for example to transport gasoline to filling stations. They also transport a wide variety of liquid goods such as concrete, milk, diesel and industrial chemicals. Smaller tank trucks, with capacity of less than 11,000 liters are typically used to deal with light liquid cargo with a local community. A common example is a septic service truck used to vacuum clean several septic tanks and then deliver the septic material to a collection site. In time of water shortage, it can be used to transport water. They are usually equipped with a pumping system to serve their particular need (Shier, 1977).

2.3.2 Tank Trailers

A tank trailer is a truck trailer equipped as a tanker, used to carry liquids such as edible oils, motor oils, petroleum products, milk, juice, waste or chemicals can also carry dry bulk such as cement, and also gas. A tank trailer is a form of a semi-trailer, which is a type of trailer that has wheels only at the rear, the front end being supported by the towing vehicle known as a tractor or a prime mover. A semi-trailer is equipped with legs that can be lowered to support it when it is unhooked from the tractor. The tank can be made of stainless steel or aluminum. The inside structure of the tank is comprised of compartments. The capacity can be from smaller 20,000 liters and can go as far as 60,000 liters.

Long-distance, international transportation of liquid chemicals is conducted using one of five modes: pipeline, bulk tankers, parcel tankers, tank containers, or drums. Pipeline and bulk tankers are used in the petrochemical industry for the transport of large quantities of a single product. Parcel tankers are smaller vessels with up to 42 tank compartments and are used to simultaneously transport multiple cargoes. Tank containers, also referred to as international organization for standardization (ISO) tanks, inter-modal tanks, or International Maritime Organization (IMO) portable tanks, and are designed for inter-modal transportation by road, rail, and ship.

2.4 TRANSPORTATION IN SUPPLY-CHAIN

Supply-chain (SC) is the integration of the activities that procure materials and services, transform them into intermediate goods and final products, and deliver them to the customers (Ibrahim, 2008).

Global supply chains (GSC) represent longer distance to travel and also more workers, which lead to more opportunities for disruptions (Sheffi, 2005 and Briggs, 2010). An example, when sourcing or labor moves abroad, either water or air, another mode of transportation, is often introduced to the SC, and the length of the SC is increased, introducing new potentials for disruption (Kelly, 2008). A disruption anywhere in the SC can have a profound effect on a corporation's performance; it eroded market share, budget and bloats cost, threatens production and distribution, and tarnishes credibility with investors and other stock holders, and sky rocket the cost of capital (Bostman, 2006). The increase in complexity of the GSC network has also resulted in an increased disruption risk.

Examples of SC disruptions are distributed into three distinct categories:

i. Intentional attacks such as sabotage, terrorism, computer hacking, labor issues.
ii. Natural disasters such as hurricanes and earthquakes
iii. Accidents such as equipment failures and fires (Sheffi, 2005).

In addition there are some regions in the developing countries where political instabilities pose some risk to the oil industries.

These supply chain disruptions are associated with a certain probability of occurrence and characterized by severity and direct effects (Kleindorfer and Saad, 2005). They can materialize from various areas internal and external to a SC (Wagner and Bode. 2006). Hurricane Mitch in the Caribbean Island, 1998; the Chi-Chi, Taiwan, earthquake of September 1999 that sent shock waves through the global semiconductor market (Papadakis and Ziemba, 2001); the August 14, 2003 blackout in the northwestern U.S.; the Y2K problems, the U.S. West Coast Ports strike, 2000; the Severe Respiratory Syndrome (SARS) Virus outbreak in Asia and Canada, 2003; the 2001 U.K Mad Cow Disease that resulted in the destruction of several thousand cattle; and certainly the September 11, 2001 terrorist attacks in the U.S; and the 2004 attacks in Madrid are just a few examples that confirms that firms and their GSC certainly operate in an unpredictable and increasingly uncertain environment (Wagner and Bode 2006).

2.5 TRANSPORTATION PROBLEMS USING SIMULATION

The search for solutions to the aforementioned problems calls for a new generation of transportation systems modeling and simulation tools. A model, in general, is commonly defined to be a simplified abstract representation of a system at a certain time point. A simulation model has the added advantage of capturing the dynamic aspect of the system and its evolution over time. Simulation and modeling are effective ways to study the transportation system as a whole, and the myriad interactions among its different elements. To study the transportation system, a professional typically develops a model, runs the model to simulate the system, and learns from the simulation result.

Simulation and modeling offers obvious advantages over the other choice - real-world experiments. Firstly, the depth of understanding that can be achieved by simulation and modeling can hardly be achieved in other ways. Secondly, the cost of simulation and modeling is much lower than that of other ways, since it does not require any building or construction in reality. Thirdly, the speed of simulation and modeling is mainly constrained by computational resources, but not physical factors, which means it is much faster and offers greater efficiency. Fourthly, in most transportation case studies, simulation and modeling is the only choice, because real-world experiments are too costly, impractical, or impossible. Therefore, simulation and modeling is an indispensible part of Intelligent Transportation Systems (ITS) (Huang, 2011).

Hughes, (1971) articulates how the orientation of management science in Mobil is that of the joint problem solving. Teams of management scientists and line management solve and implement solutions to problems with terms of reference given by senior management. This has resulted in an effective program, which is illustrated here by the work in one aspect of the oil industry, the distribution of products from refinery to the customer. He explains that the problem on hand is to deliver fuel to the customer at a minimal total cost and time. Hughes sets up a network model to determine where to locate the terminals with respect to customer distribution sites. The emphasis is to optimize distribution costs from the refinery terminal to the customer, which aligns with one scope of this study.

Bell, (1980) discusses how a two-stage production system, generated by a stochastic process, can help the firms to optimize storage facility capacities. He sets up the problem by highlighting that production (stage one) and demand (stage two), in a given period, are independently distributed random variables and are outside management's control. The objective is to evaluate different storage capacities, transfer rates and production levels to optimize long run plant configuration. The stages are decoupled by storage of intermediate product, but there are strict limits on the available storage capacity, and the rates of flow of product into, and out of, the decoupling inventory. Product, which cannot be stored, is wasted. A model is formulated which enables the firm to determine the optimum capacities for the storage facility, and to determine the value of an additional supply of intermediate product. Bell uses an example of a chemical plant, which has three plants with six different locations for processing ethylene gas. The model allows for schedule maintenance and shutdowns. The model is supported by understanding probability distributions of demand and production rates and incorporating the holding cost required to maintain gas in inventory and the value of capital associated with this inventory. The analysis involved a computer program that calculated the steady state probabilities of the plan operating data and conducting experimentation on variables to understand the impact on meeting demand, storage tank utilization and inventory holding cost. Bell concludes by showing that the model, given a set of decision variables, is able to predict storage tank requirements that will balance the shortage cost and the cost of holding inventory along with the cost of flaring excess gas. He does not explore the cost optimization of storage versus transportation, leaving grounds for further studies to be conducted in this area.

Guldmann, (1983) discusses the trade-offs among purchases, storage and service reliability decisions faced by natural gas distribution utilities. To explore these trade-offs, a chance-constrained cost minimization problem is formulated where decision rules for gas purchases and storage operations are examined. An initial decision is made at the beginning of each month about either the level of purchases or the level of storage flow for that month. This analysis assumes that the *Number of Tanks* and *Tank Capacity* are fixed and it does not account for the transportation required to fulfill customer orders form the storage reservoirs. However, the algorithm presented for examining level of storage flow and level of purchase for a particular month does, to a certain extent, influence the oil terminal operation profitability.

Sear, (1993) describes the great importance of logistics chain planning within the downstream petroleum industry. Logistics networks originate at refineries and terminate at the final delivery point - the customer. Types of bulk transportation used and the main product classes are described. The business decisions, which need to be addressed, are stated. A corresponding model is formulated partly in mathematical and partly in qualitative terms. The cost of road vehicle delivery to customers is modeled. The business risks associated with changes to the logistics infrastructure are indicated. Sear focus in transportation from refineries to customer. Study does not address any profitability concerns of the storage facilities.

McVay, (2001) showed that gas storage has become increasingly important in managing the nation's gas supplies. He argued the need for more effectively managing gas storage reservoirs. His solution is to maximize working gas volume and peak rates for a particular configuration of reservoir, well and surface facilities. McVay developed a simple procedure to determine the maximum performance with a minimal number of simulation runs. The first step was to determine the maximum working gas capacity for operations between fixed pressure limits. He achieved this by preparing a reservoir model, production performance curves, injection performance curves and then projecting from these curves, the cushion gas requirements and working gas capacity. Furthermore, McVay presented one possible solution to minimize cost. He focused on cost minimization to satisfy a specific production and injection schedule, which is derived from the working gas volume and peak rate requirements. McVay demonstrates a systematic procedure to determine the optimum combination of cushion gas volume, compression horsepower, and number and locations of wells. He determined the optimum gas storage reservoir design using a series of simulation experiments. This was achieved by first selecting a minimum compressor intake pressure and then gradually increasing the pressure intake to determine the number of walls required to make the production schedule while staying within predefined pressure constraints. This is a good approach to identify *Tank Capacity*, number of wells (or tanks) and gas flow rate required to meet demand. However, the author did not address how to optimize costs incurred to maintain oil terminals and trucks. Additionally, the article does not address profitability numbers for the gas storage reservoirs.

Macro and Samli (2002) and Yun and Choi (1999) covered application of simulation tools to efficiently allocate resources. Similar strategic planning problems have been studied extensively and most of them focused on the reduction of traveling cost and handling cost within the system. These articles do not address any profitability concerns of the storage facilities.

Kleijnen (2005) indicated simulation as a tool of methodological concerns: verification, sensitivity or “what-if” analysis, optimization, and robustness and uncertainty analysis for strategic levels. He surveyed four types of simulation, and discussed four methodological issues. These four simulation types are spreadsheets, system dynamics (SD), discrete-event dynamic systems (DEDS) and business game. This study provide an intelligent system with a user interface window to help the decision maker to choose and evaluate the important decision factors to maximize the total profit and minimize the total transportation cost.

Mes et al. (2007) consider the real-time scheduling of full truckload transportation orders with time windows that arrive during schedule execution. They introduce an agent-based approach where intelligent vehicle agents schedule their own routes. They interact with job agents, who strive for minimum transportation costs, using a Vickrey auction for each incoming order. They compare the agent-based approach to more traditional hierarchical heuristics in an extensive simulation experiment. They offer several advantages: it is fast, requires relatively little information and facilitates easy schedule adjustments in reaction to information updates. This study attended two different methods to find the optimal total profit and transportation cost.

Cho and Prabhu (2007) developed a unified control system using a continuous control theoretic approach for distributed production scheduling in highly autonomous manufacturing environment. They considered multi-criteria objectives such as production rate and due date deviations and developed distributed controller to manage both job scheduling and machine capacity simultaneously. They not mention about the profitability and the transportation cost

Karim et al. (2009) developed the simulation model using continuous control approach for machine capacity allocation and real-time scheduling. These control theoretic approaches can be applied to the transportation problem due to the similarities of the performance measures and problem environments. They do not address any profitability concerns of the storage facilities.

Xi et al. (2009) addressed problem of yard crane dispatching in container terminals. They proposed two hybrid algorithms which combine the advantages of A* heuristic search and Recursive Backtracking with prioritized search order to accelerate the solution process. The algorithms proposed use real time data-driven simulation to accurately predict the time taken by the yard crane in performing its operations. This study developed an integrated system using DES and LP to manage the profitability and transportation cost.

Seokgi et al. (2010) used Meta heuristic or simulation methods rather than optimization approaches to reflect demand changes into existing solutions due to computational complexity. The important issue of heuristic or meta heuristic for the vehicle routing scheduling is to find appropriate methods to diversify search space and intensify routing solution to reduce both transportation cost and time gap from demands. Along with these common approaches, control theoretic approaches based on discrete event simulation have been developed. They do not address any profitability concerns of the storage facilities.

Bigotte et al. (2010), a problem addressed during the preparation of spatial development plans relates to the accessibility to facilities where services of general interest such as education, health care, public safety, and justice are offered to the population. In this context, planners typically aim at redefining the level of hierarchy to assign to the urban centers of the region under study (with a class of facilities associated with each level of hierarchy) and redesigning the region’s transportation network. This paper presents an optimization model that simultaneously determines which urban centers and which network links should be promoted to a new level of hierarchy so as to maximize accessibility to all classes of facilities. This study provides assignment solution for petroleum transportation from a refinery to a depots using LP.

Çapar et al. (2011), this article deals with a two-stage supply chain that consists of two distribution centers and two retailers. Each member of the supply chain uses a (order quantity and reorder point) inventory policy, and incurs standard inventory holding and backlog costs, as well as ordering and transportation costs. They develop a decision rule that minimizes the total expected cost associated with all outstanding orders at the time of order placement; the retailers then repeatedly use this decision rule as a heuristic. A simulation study which compares the proposed policy to three traditional ordering policies illustrates how the proposed policy performs under different conditions. This article did not mention the profitability concerns of the storage facilities.

2.6 TRANSPORTATION PROBLEMS USING MATHEMATICAL PROGRAMMING

In 1941, Hitchcock first developed the transportation model. Dantzig (1963) then uses the simplex method on the transportation problem as the primal simplex transportation method. The modified distribution method is useful in finding the optimal solution for the transportation problem. Charles et al. (1953) developed the stepping stone method, which provided an alternative way of determining the simplex method information.

Article on vehicle routing problem (VRP) was, originally posed by Dantzig et al. (1980). The VRP is commonly defined as the problem of designing optimal delivery or collection routes from one or several depots to a set of geographically scattered customers, under a variety of side conditions. Location-routing problems (LRPs) are VRPs in which the optimal depot locations and route design must be decided simultaneously.

Daellenbach, (1977) explores how firms have a limited number of bulk storage tanks available for intermediate storage and how an inventory stocking and replenishment system can benefit the firm. The problem is to determine an assignment model of n storage tanks to m different products that are being sold. Also, a stocking rule for the m products is required. Using an optimization approach, he creates a linear program with a set of given constraints to show that in a common situation when the number of bulk tanks is less than the number of different products sold, then it is advantageous to require that bulk order processing time be at least as large as mixing lead time. It is shown that for a given inventory policy, the minimization of the total cost expression can be transformed into a nested optimization problem involving three phases. These can be optimized sequentially starting with the innermost phase. The last phase turns out to be a transportation problem. The optimal solution is that allocation tends to assign products with high mixing set-up costs and low handling costs to tanks, while products with low mixing set-up costs and high handling costs are left unassigned. Although the attempt has been made to reduce cost by setting by the heuristic model for a re-order point, once again, the optimization of lease cost versus transportation cost and overall storage tank profitability remains to be explored.

Roy and Gelders (1981) solved a real life distribution problem of a liquid bottled product through a 3-stage logistic system; the stages of the system are plant-depot, depot-distributor and distributor-dealer. They modeled the customer allocation, depot location and transportation problem as a 0-1 integer programming model with the objective function of minimization of the fleet operating costs, the depot setup costs, and delivery costs subject to supply constraints, demand constraints, truck load capacity constraints, and driver hours constraints. The problem was solved optimally by branch and bound, and Langrangian relaxation.

Christofides et al. (1980) explore the efficient ways of loading (and unloading) into (and out of) storage tanks at oil terminals. In this study, the number and size of storage tanks are pre-determined. What is required is to perform a sequence of loading and unloading activities to determine the best method of operation. The study formulates a mixed integer program with continuous variables. The problem was exercised on real life examples involving 45 loading and unloading operations, 11 different types of fluids and 20 storage tanks. The study does not explore the optimization of storage tanks and sizes. Furthermore, the transportation costs involved in loading and unloading these storage tanks are not investigated. Additionally, the article does not address the terminal profits.

Brown and Graves (1981) show how a real-time dispatch system can be optimized to reduce operating costs of a nation-wide fleet of petroleum tank trucks. The objective of this article is to minimize transportation costs while maintaining equitable human and equipment workload distribution, safety standards and customer service. An integer linear programming model is incorporated to show how several coordination issues can be easily managed to optimize transportation costs. The results are very encouraging compared with manual dispatches; this system produces extremely uniform distribution among vehicles with significantly lower costs. The article, however, does not address how the terminal system can be optimized to produce the highest profitability for the operation.

Fisher and Jaikumar (1981) developed a generalized assignment for vehicle routing. They considered a problem where a multi-capacity vehicle fleet delivers products stored at a central depot to satisfy customer orders. The routing decision involves determining which of the demands will be satisfied by each vehicle and what route each vehicle will follow in servicing its assigned demand in order to minimize total delivery cost. They claim their heuristics will always find a feasible solution if one exists, something no other existing heuristics (until that time) can guarantee. Further, the heuristics can be easily adapted to accommodate many additional problem complexities.

Nambiar et al. (1989) solved a large-scale location-allocation problem in the Malaysian natural rubber industry using their own heuristic approaches. They formulated a minimization of overall costs objective function which consisted of travel and return costs of collecting latex from collecting stations to central factories, vehicle fixed charges, fixed charges for operating central factories and overtime costs for lorry crews. The problem was decomposed into a plant location part and a vehicle routing part. Laporte et al. (1988) examined a class of asymmetrical multi-depot vehicle routing problems and location-routing problems, under capacity or maximum cost restrictions. The problem was formulated as a traveling salesman problem (TSP) in which it is required to visit all specific nodes exactly once and all non-specified nodes at most once. And, there exist capacity and maximum cost constraints on the vehicle routes; plus, all vehicles start and end their journey at a depot, visit a number of customers and return to the same depot.

Leung et al. (1990) develop an optimization-based approach for a point-to-point route planning that arises in many large-scale delivery systems, such as communication, rail, mail, and package delivery. In these settings, a firm, which must ship goods between many origin and destination pairs on a network, needs to specify a route for each origin-destination pair so as to minimize transportation costs. They developed a mixed multi-commodity flow formulation of the route planning problem, which contains sixteen million 0-1 variables, which is beyond the capacity of general integer programming (IP) code. The problem was decomposed into two smaller sub-problems, each amenable to solution by a combination of optimization and heuristic techniques. They adopted solution methods based on Langrangian relaxation for each sub-problem.

Saumis et al. (1991) considered a problem of preparing a minimum cost transportation plan by simultaneously solving the following two sub-problems: first the assignment of units available at a series of origins to satisfy demand at a series of destinations and second, the design of vehicle tours to transport these units, when the vehicles have to be brought back to their departure point. The original cost minimization mathematical model was constructed, which is converted into a relaxed total distance minimization, then finally decomposed into network problems, a full vehicle problem, and an empty vehicle problem. The problems were solved by tour construction and improvement procedures. This approach allows large problems to be solved quickly, and solutions to large test problems have been shown to be 1% or 2% from the optimum.

Achuthan et al. (1996) wrote an Integer Programming model to solve a vehicle routing problem (VRP) with the objective of distance minimization for the delivery of a single commodity from a centralized depot to a number of specified customer locations with known demands using a fleet of vehicles that a have common capacity and maximum distance restrictions. They introduced a new sub-tour elimination constraint and solved the problem optimally using the branch and bound method and used the CPLEX software to solve the relaxed sub-problems.

Tzeng et al. (1995) solved the problem of how to distribute and transport the imported coal to each of the power plants on time in the required amounts and at the required quality under conditions of stable and supply with least delay. They formulated a LP that minimizes the cost of transportation subject to supply constraints, demand constraints, vessel constraints and handling constraints of the ports. The model was solved to yield optimum results, which is then used as input to a decision support system that help manage the coal allocation, voyage scheduling, and dynamic fleet assignment.

Fisher et al. (1995) worked on a problem in which a fleet of homogeneous vehicles stationed at a central depot must be scheduled and routed to pick up and deliver a set of orders in truckload quantities. They defined schedule as a sequential list of the truckload orders to be carried by each vehicle, that is, where the bulk pickups and the delivery points are. They solved the problem by a network flow based heuristic, and claimed their algorithm consistently produces solutions within 1% of optimality.

A major oil company in the United States has dispatchers that are responsible for assigning itineraries to drivers to pick up crude products, using homogeneous capacity tank trucks, at designated locations for delivery to pipeline entry points. Bixby and Lee (1998) solved the problem to optimality with up to 2000 variables, applying branch and cut procedures on 0-1 IP formulations.

(Brandao and Mercer 1996; Zhang and Moon 2009) used the tabu search heuristic to solve the multi-trip vehicle routing and scheduling in a real distribution problem, taking into account not only the constraints that are common to the basic routing problem, but also the following; during each day a vehicle can make more than one trip, customers delivery time windows, multi capacity vehicles, access to some customers is restricted to some vehicles, and drivers have maximum driving time with breaks.

Equi et al. (1996) modeled a combined transportation and scheduling in one problem where a product such as sugar cane, timber or mineral ore is transported from multi origin supply points to multi destination demand points or transshipment points using carriers that can be ships, trains or trucks. They defined a trip as a full-loaded vehicle travel from one origin to one destination. They solved the model optimally using Langrangean Decomposition.

McCann (1996) argued that total costs of distance are greater than simply transportation costs. The reason is that transportation costs are only one component of total logistics costs, which also include inventory holding and purchasing costs, and these total logistics costs can be shown to be directly related to haulage distance.

Further, he showed that the interregional mobility of a firm will depend on the price of the goods being shipped.

(Jayamaran, 1998; Zegordi et al., 2010) formulated a mixed Integer programming model that looked into the relationship between inventory, location of facilities and transportation issues in a distribution network design. The formulation involves minimizing the cost of warehouse and plants location, inventory related costs and transportation costs of products from open plants to open warehouses and costs to deliver the products from warehouses to customer outlets.

Kim and Pardalos (1999) considered the fixed charge network flow problem, which has many practical applications including transportation, network design, communication, and product scheduling. They transformed the original discontinuous piecewise linear formulation into a 0-1 mixed IP problem to solve very large problem of up to 202 nodes and 10,200 arcs using a heuristics called dynamic slope scaling procedure that generate solutions within 0% to 0.65% of optimality in all cases.

Budenbender et al. (2000) worked on a network design problem for letter mail transportation in Germany with the following characteristics; freight has to be transported between large number of origins and destinations, to consolidate it is first shipped to a terminal where it is reloaded and then shipped to its destination. The task is to decide which terminals have to be used and how the freight is transported among terminals. They modeled the problem as a capacitated warehouse location problem with side constraints using mixed IP and solved by a hybrid tabu search / branch-and-bound algorithm.

(Irnich, 2000; Yim et al., 2011) introduced a special kind of pickup and delivery problem, called ‘multi-depot pickup and delivery problem with a single hub and heterogeneous vehicles’. All request have to be pickup at or delivered to one central location which has the function of a hub or consolidation point. In hub transportation network routes between customers and the hub are often short; involve only one or very few customers. The problem primarily considers the assignment of transportation request to routes. The author concludes that many problems in transportation logistics can be modeled and solved similarly whenever routes can be enumerated and the temporal aspects of transportation requests are important.

Diaz and Perez (2000) applied the simulation optimization approach proposed by Vashi and Bienstock (1995) to solve the sugar cane transportation problem in Cuba that involved thousands of workers, dozens of cutting machines, hundreds of tractors and several hundreds of truck and trailers.

Li and Shi (2000) formulated a dynamic transportation model with multiple criteria and multiple constraint levels (DMC^2) using the framework of multiple criteria and multiple constraints (MC^2) LP. An algorithm is developed to solve such DMC^2 transportation problems. In this algorithm, dynamic programming ideology is adopted to find the optimal sub-policies and optimal policy for a given DMC^2 transportation problem. Then the MC^2-simplex method is applied to locate the set of all potential solutions over possible changes of the objective coefficient parameter and the supply and demand parameter for the DMC^2 transportation problem.

The classical vehicle routing problem (VRP) consists of a set of customers with known locations and demands, and a set of vehicles with limited capacities, which are to service the customers from a central location referred to as depot. The routing problem is to service all the customers without overloading the truck, while minimizing the total distance traveled and using minimum number of trucks. Thangiah and Salhi (2001) studied a multi depot vehicle routing problem with vehicles starting from different depots, which is an extension of the classical VRP. They solved the problem by a generalized clustering method based on a genetic algorithm, called genetic clustering.

(Doerner et al., 2001; Garaix et al., 2010) solved a problem for a logistics service provider to satisfy a set of transportation requests between distribution centers. Each order is characterized by its size, it fills a truck completely, and its time window for pickup and delivery. Since consolidation is not an option, each order is transported directly from its source to its destination. The available fleet is distributed over the distribution centers, and each vehicle is constrained by a maximum tour length restrictions. The minimum fleet-size and minimum distance problem was solved by ant colony optimization.

Chao (2002) studied the truck and trailer routing problem, which is a variant of the vehicle routing problem. The problem looked into some real-life applications in which fleet of m_k trucks and m_l trailers ($m_k \geq m_l$) services a set of customers. There are three types of routes in a solution to the problem: (1) a pure truck route traveled by a truck alone, (2) a pure vehicle route without any sub-tours traveled by a complete vehicle, and (3) a complete route consisting of a main tour traveled by a complete vehicle, and one or more sub-tours traveled by a truck alone. A sub-tour begins and finishes at a customer on the main tour where the truck uncouples, parks, and re-couples its pulling trailer and continues to service the remaining customers on the sub-tour. The objective is to minimize the total distance traveled, or total cost incurred by the fleet. He solved the problem by tabu search and deterministic annealing.

Wang and Regan (2002) describe a solution method for a multiple travel salesman problem with time window constraints to develop vehicle assignment for a local truckload pickup and delivery. The integer 0-1 model was developed with the objective to minimize total transportation cost with fleet size fixed, vehicles to pick up and leave each load at most once, vehicles departs from a load only if it serves the load first, and time window requirements. The model was run to optimality using CPLEX version 5.0

Wu et al. (2002) proposed a decomposition-based method for solving the location-routing problem (LRP) with multiple depot, multiple fleet types, and limited number of vehicles for each different vehicle type. Like in any LRP it is assumed that the number, location, and demand of customers, the number, and location of all potential depots, as well as the fleet type and size are given. The distribution and routing plan must be designed so that; the demand of each customer can be satisfied, each customer is served by exactly one vehicle, the total demand on each route is less than or equal to the capacity of the vehicle assigned to that route, and each route begins and ends at the same depot. Decision must be made on the location for factories/warehouse/distribution centers DC, referred as depots. Also, the allocation of customers to each service area must be decided. Transportation must be planned to connect customers, raw materials, plants, warehouses, and channel members. They formulated the mathematical problem to solve the above decisions simultaneously with the objective function to minimize the depot setup cost, delivery cost and the dispatching cost for the vehicles assigned subject to the following constraints (1) each customer assigned on a single route (2) vehicle capacity (3) sub-tour not allowed (4) flow conservation (5) each route served at most once (6) capacity for DC (distribution center) (7) customer assigned to DC if there is a route from that DC through that customer. This problem was solved using simulated annealing.

Gigler et al. (2002) applied dynamic programming (DP) in the supply chain of agricultural commodities, or what they called as agri chains. They applied DP methodology specifically in a case of the supply chain of willow biomass fuel to an energy plant. Included in the DP approach not only transportation but also various stages of handling (harvesting) and processing (natural drying) of the biomass fuel.

The fixed charge transportation problem is an extension of the classical transportation problem in which a fixed cost is incurred, independent of the amount transported, along with a variable cost that is proportional to the amount shipped. The fixed charge factor makes the objective function discontinues, thus making model difficult to solve. Adlakha and Kowalski (2003) propose a simple heuristic to solve the problem.

Navani et al. (2002) present invention provides software that includes various tools of computer for the different individuals (crude and product traders, planners/analysts, brokers, schedulers, vessel owners/brokers, terminal operators, pipeline operators and cash brokers, etc.) involved in oil trading. In preferred embodiment, invention system is an on-line, real-time user interactive software system. invention system includes three pieces of functionality: decision support tools: a broad set of powerful tools for accurate, on-the-fly deal evaluation and decision making including crude oil evaluation, product component blending and trading, arbitrage identification, transportation and vessel selection optimization. deal negotiation system: a secure and private environment for bid/offer transaction for physical petroleum commodity trading, seamlessly integrated with collaborative workflow and decision support tools. This invention is similar to our research as it also relates to evaluating the most economical method from dealing with the crude oil price to deliver the product to its destination, and he uses parameters related to marketing variables. Capacity transported, and cost rate found to obtain in that invention. The software utilizes the usage of network to find several of options before the data collected are being optimized and shows best option to transport the crude oil. This is different from our research where the data are collected and set as input manually to enable the mathematical linear programming used to find the best node to transport crude oil. However, our research has an advantage where a simulation can be screened to the user for simulating the transportation flows, which is not found in that invention.

Gronalt et al. (2003) studied pickup and delivery of truckloads under time window constraints. A logistic service provider studied, accepts orders from customers requiring shipments between two locations, and serves the orders from a number of distribution centers. Thus, shipments occur between the pickup location of an order and the closest distribution center, between distribution centers and between a distribution center and the delivery location of an order. The problem was formulated as a mix integer program with the objective of minimizing empty vehicle movement, and solved using a heuristic known as saving algorithm proposed by Clark and Wright (1963).

Cheung and Hang (2003) studied a routing problem for a land transportation of air-cargo freight forwarders in Hong Kong, which allows time windows, backhauls, heterogeneous vehicles, multiple trips per vehicle and penalty for early arrival at customer sites. They formulated an IP to minimize the traveling costs and waiting costs subject to demand constraints, continuous flow of the vehicle constraints, time window constrains, and capacity constraints. They developed two optimization-based heuristics to solve the problem, and using real data they showed that the model produce quality solutions quickly and are flexible in incorporating complex constraints.

Berger and Barkaoui (2003) solved the capacitated VRP with the objective of distance minimization subject to customers known demands and time windows, homogeneous fleet of vehicles, and vehicles initially located and end at a central depot. They applied their own new hybrid Genetic Algorithm (GA).

Faulin (2003) modeled a vehicle routing LP problem for a frozen food company that had to deliver the goods to customers with unknown fleet size, homogeneous fleet, a single depot, and deterministic demand. The objective function was distance minimization. The model was solved by creating and implementing software called MIXALG, which consist of subroutines (heuristic and exact) that are dedicated for solving transportation-distribution problems to optimality.

Adlakha and Kowalski (2003) solved a small fixed-charged transportation problem by a simple heuristic. The fixed-charged transportation problem (FCTP) is an extension of the classical transportation problem in which a fixed cost is incurred, independent of the amount transported, along with a variable cost that is proportional to the amount shipped. The FCTP can be stated as a distribution problem in which there are m suppliers and n customers. Each of the m suppliers can ship to any of the n customers at a shipping cost per unit c_{ij} plus a fixed cost f_{ij}, assumed for opening this route. Each supplier i = 1, 2,…, m has a_i units of supply, and each customer j = 1,2,…,n has a demand of b_j units. The objective is to determine which routes are to be open and the size of the shipment on those routes, so that the total cost of meeting demand, given the supply constraints, is minimized.

Determining the fleet size is the most fundamental decision in a transportation system whose capacity is directly related to the number of available vehicles. Koo et al., (2004) solved the fleet size problem given the total vehicle time in the planning horizon. The situation modeled was the massive movements of containers between container terminal at the port in the port area of Busan, Korea, and container yards scattered in the city. The problem was simplified by a model where the objective function was to minimize the total empty vehicle travel time subject to vehicle flow in and out (at a location) constraints. The problem was solved using tabu search.

Guy and Nelson (2004) disclosed a method of forming a schedule of crude oil shipments being received at a refinery facility using a genetic algorithm (GA) has been developed. A period of time, T, within which the oil shipment schedule is to be formed, is determined. A first generation of chromosomes is generated and a fitness function value calculated for every chromosome. A succeeding generation of the chromosomes is created using a GA and the fitness function value for each chromosome is determined. Steps of the producing a succeeding generation of chromosomes using a GA and determining a fitness function value for each chromosome are repeated for time T. Chromosome having the highest fitness function value within time T is identified to generate the schedule. This invention is similar to our study as it also a method to increase efficiency to transport crude oil or petroleum and a generic algorithm is used to find the most efficient time to transfer the crude oil. This is similar to the parameters used for determining the mathematical linear programming in this study. However, our research is showing multiple results to enable the user to select the best method to transport the crude oil depending on the situation. In addition, the study has a real time simulation to allow the user to observe the transporting flow clearly, which is not found in that invention.

Jula et al. (2005) modeled full-truck-load ISO container trucks movement with time constraints at origins and destinations as an asymmetric multi-traveling salesman problem with time windows. Each truck daily movement starts empty from a depot visits various origin-destination pairs to do the full-truck loading and unloading its cargos and return to the depot empty. Each origin-destination pair was treated as a node, and their objective was to minimize the empty miles connecting the nodes. DP was applied to yield optimal solution for small size problems. Hybrid DP with GA was capable to find sub-optimal solution for medium to large size problems (more than 30 nodes). The insertion heuristic method was able to find relatively good solution for large size problems.

Chu (2005) solved the food and beverages delivery problem from a warehouse to customers with known demand, for a company that uses both truckload and less-than-truckload vehicles. Truckloads are operated by own heterogeneous fleet of vehicles and less-than-truckload are selected from private carriers. He developed a mathematical model and solved using his own heuristics.

Mitra (2005) developed a mixed integer linear programming (MILP) to solve a vehicle routing problem with backhauling. It involved with the supply of finished goods from a depot to a number of delivery points, and picking up returnable items and bringing them back to the depot using a fleet of trucks. The objective was to minimize the total route costs subject to the following constraints (1) demand (2) retuning goods (3) number of trucks, and (4) truck balance. The problem was solved using a route construction heuristic.

Gribkovskaia et al. (2006) modeled and solved optimally a mixed integer programming (MIP) for the livestock transportation in Norway that combine vehicle routing and inventory. They introduced the possibility of multiple routes for a given vehicle on a given day in a multiple-period planning perspective. Arrival times of the loaded vehicle to the slaughterhouse are controlled by production (slaughter) rate and inventory level at the abattoirs so that the supply of animals for slaughter is steady and production breaks are avoided. Livestock welfare is taken in consideration by the route duration constraints. Their objective was minimization of travel time subject to one visit per farm; vehicle starts and ends at depot, vehicle continuity flow, vehicle capacity, compatibility requirement between routes and schedules, multiple uses of vehicles, animal welfare requirements and linking routing with production/inventory constraints.

Tan et al. (2006) considered a transportation problem for moving empty or laden containers. Owing to limited resources of its vehicles (truck and trailers), the company often needs to sub-contract certain jobs to outsourced companies. A model for this truck and trailer vehicle routing problem is constructed with the objective to minimize routing distance and number of trucks, subject to constraints such as time windows and availability of trailers. The multi-objective with multi-modal combinatorial optimization problem was solved by evolutionary algorithms.

Muhamad et al. (2006) developed an IP problem for a transportation company that collected CPO from various mills to a central depot in Klang port, Malaysia using multi capacity truck tankers. Benjamin et al. (2006) studied on the workload balance aspect of the drivers for the same company. They balanced the tonnage hauled and the distance traveled simultaneously for all the 46 drivers in a given month. The ILOG software was used to solve the optimization problem.

Nagy and Salhi (2007) did a survey of location - routing, which they take to mean location analysis that takes into account vehicle routing aspects. They presented application areas where LRP have been studied, they are; food and drink distribution, consumer goods distribution, blood bank distribution, newspaper distribution, rubber plant location, goods distribution, postbox location, grocery distribution, waste collection, military equipment location, medical evacuation, bill delivery, optical network design, parcel delivery, telecom network design, and shipping industry. They classified LRP into; hierarchical structure, type of input data, planning period, solution method, objective function, solution space, number of depots, number and type of vehicles, and route structure. Exact solution methods for deterministic problem mentioned in their paper are cutting plane, branch-and-bound, numerical optimization, branch-and-cut, and graph theory.

Dondo and Cerda (2007) proposed a cluster based optimization approach for solving the multi-depot heterogeneous fleet vehicle routing problem with time window. Customers wanted known amounts of their goods to be picked up and delivered at specified locations. Decisions must be made on the number and types of vehicles to be used and for each customer which vehicle must be used and the sequence to follow so as to minimize the transportation cost. A mixed integer linear programming model was formulated in which the objective was to minimize service expenses, including fixed vehicle utilization costs, travel distance and time costs, waiting and service time costs and penalty costs. The constraints are (i) every route must start and end at the same depot; (ii) each customer must be serviced by just a single vehicle; (iii) the total load assigned to any vehicle must never exceed its cargo-capacity; (iv) the length of service time for any vehicle must never exceed its allowed working time; (v) a penalty is imposed if pick-up or delivery is done outside the time window.

Jozefowiez et al. (2008) surveyed the existing research related to multi-objective optimization in routing problems. They examined routing problem in terms of their definitions, their objectives, and the multi-objective algorithms proposed for solving them. Interesting to note that their survey, stated some real-life multi-objective routing cases studied before, such as; transport delivery routing, urban school bus route planning, rural school bus routing, urban trash collection, merchandise transport routing, hazardous product distribution, multi-period vehicle routing, and tour planning for mobile healthcare facilities.

Baykasoglu and Kaplanoglu (2008), there are many studies in the literature that explain modern costing approaches including activity-based costing (ABC). One of the main difficulties in land transportation companies is to determine and evaluate true cost of their operations and services. ABC can be very helpful for transportation companies to determine cost of their operations with higher correctness. In this article, an application of ABC to a land transportation company that is located in Turkey is presented in detail. In order to improve the effectiveness of the ABC an integrated approach that combines ABC with business process modeling and analytical hierarchy approach is proposed.

Bianco and Giordani (2009) consider the following hazmat transportation network design problem. A given set of hazmat shipments has to be shipped over a road transportation network in order to transport a given amount of hazardous materials from specific origin points to specific destination points. In particular, the aims to minimize the total transport risk induced over the entire region in which the transportation network is embedded, while local authorities want the risk over their local jurisdictions to be the lowest possible, forcing the regional authority to assure also risk equity. They provide a linear bilevel programming formulation for this hazmat transportation network design problem that takes into account both total risk minimization and risk equity.

Loo Hay et al. (2010) studies the modeling and optimization for the flight assignment plan for an air cargo inbound terminal. A multi-objective MIP model is formulated to determine this plan. A set of non-dominated solutions are obtained by solving this multi-objective model and they are further analyzed by a simulation model to identify the best one.

Satar and Peoples (2010), a generalized shipper transportation cost function is estimated to test whether coal shippers achieve allocative efficiency with respect to market prices when facing limited access to full range of the transportation services. Findings indicate that allocative efficiency with respect to market prices is achieved when shippers have access to all major transportation modes. In contrast, condition for allocative efficiency is not met with respect to the market prices when shippers' modal choices are limited to trucking and rail services.

Zhao et al. (2010) addresses some of the challenges faced by a company which is responsible for delivering coal to its four subsidiaries situated along a river, through river hired or self-owned vessels. They propose to adopt a vendor managed inventory concept that involves the establishment of a central warehouse at the port, and apply Markov Decision Process (MDP) to formulate both ordering and delivery problems, considering different transportation modes, costs, and inventory issues. They developed an efficient algorithm for solving the MDP models.

Gary et al. (2010) provided a method and apparatus for optimal transporting of cargo. Method includes optimizing a plurality of the transportation decisions and mechanically transporting cargo through movement of a plurality of vehicles in accordance with a set of optimized transportation decisions. Decisions include the transportation routes and schedules for transportation vehicles, allocation of cargo to be transported to one or more than one demand locations by the transportation vehicles, nomination of cargo pickup by transportation vehicles from one or more supply locations, use of specialized transportation locations, and vehicle assignments for each of the transportation vehicles. Set of decisions is optimized by collecting the data relating to various transportation decisions, using data collected as part of a mixed integer linear programming model, and obtaining a solution to model to arrive at a set of optimized decisions of the transportation. This invention is similar to our study as it also relates to optimizing the transportation of a material and a linear programming model is used for optimizing the transportation vehicle of a material. Our research is used the mathematical linear programming to find the best node to transport petroleum. However, our research appears to have a simulation model which simulate real time situation of the flow of transportation and also is used multifactor analysis to find the optimal values for each parameters, which is not found in that invention.

Song et al. (2010) developed a system loaded on a computer readable medium, a computer apparatus comprising the same, and process employing the same, is described herein. computer applications, when executed, causes a computer to optimize, for maximum the net profit margin, product allocation, transportation routing, transportation vehicle/route scheduling and, optionally, blending, of bulk products that are produced by and loaded from supply locations and delivered to and consumed by the demand locations, using a heterogeneous fleet of the transportation vehicles over a pre-defined period of the time. This study is used the mathematical linear programming to find the best node to transport petroleum. However, this research includes additional system to simulate the result to the user, which is not found in that invention.

2.7 SUMMARY

In summary, there are some research in the literature that addresses oil refinery terminal optimization costs but do not consolidate the three important factors contributing to the oil terminal profitability namely, the number of tanks, the tank sizes and the truck arrival rate. Also they not integrated DES and LP. The literatures also discussed the importance of oil terminals in storage of petroleum and natural gas products and the necessity for optimizing the oil terminals operations, which presents an opportunity to further explore oil terminal optimization.

Finally there are four inventions that are related with this study which have some of similarities and difference in the methodology and the results is illustrated as in Table 2.1.

Table 2.1: The difference between the study and related inventions

Patent Literature	Differences
Navani et al. (2002)	• Software that includes various tools of computer for the different individuals (crude, planners, brokers, vessel owners, terminal operators, etc.) involved in oil trading. • Uses parameters related to marketing variables. Capacity transported, and cost rate found to obtain in that invention • This study has an advantage where a simulation can be screened to the user for simulating the transportation flows, which is not found in that invention.
Guy and Nelson (2004)	• This invention used a generic algorithm to increase efficiency and to find the most efficient time to transport crude oil. • This study is showing multiple results to enable the user to select the best method to transport the crude oil depending on the situation. In addition, the study has a real time simulation to allow the user to observe the transporting flow clearly
Song et al. (2010)	• A system loaded on a computer readable medium, for maximum the net profit margin, product allocation, transportation routing, transportation vehicle/route scheduling, using a heterogeneous fleet of the transportation vehicles over a pre-defined period of the time. • This study is used the MLP to find the best node to transport petroleum and include additional system to simulate the result to the user.
Gary et al. (2010)	• Disclosed and provided a method and apparatus for optimal transporting of cargo. Using data collected as part of a mixed integer linear programming model. • This study is used the mathematical linear programming to find the best node to transport petroleum. Also we have a simulation model which simulate real time situation of the flow of transportation.

CHAPTER 3

DEVELOPING A SIMULATION MODEL

3.1 INTRODUCTION

"Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies within the limits imposed by a criterion or set of criteria for the operation of the system" (Shannon, 1976). In a discrete event simulation (DES) model, the state of the system can only change at a discrete set of points in time. In this chapter, a simulation model of oil storage operations is developed. Then the output analysis is performed to draw conclusions from the model. The scope of the simulation model and the variable definitions are illustrated in this chapter.

3.2 SYSTEM DESCRIPTION

Oil refinery terminals are mostly used to save various liquids and gases such as chemicals, crude oil and natural gas as depicted in Figure 3.1. Petroleum products are in high demand for by various industries heating, manufacturing, vehicle fuel, lubricants, etc. Oil companies have abundant resources of petroleum products both in storage tanks and in pipelines.

Figure 3.1: Oil storage tanks

When oil is not required for immediate use, it may be stored in large tanks, owned by the oil and gas companies, or rented at a transport company's oil terminal. From a major pipeline as depicted in Figure 3.2, the oil storage tanks receive regular oil which arrives in batches from the pipeline. It then enters into one of the several tanks, each holding up to its maximum capacity. Trucks arrive at a certain average rate at the refinery, and then trucks will wait in a central queue until a tank is ready for oil loading. Tank readiness is defined as having oil which is equal to *Truck Capacity* that is available in the current tank. No truck is allowed to queue in front of the tank after completing the loading. If truck arrives at the terminal and the number of trucks currently in queue at the central queue is equal to the *Queue Capacity* then the arriving truck will balk to the truck depot. After completing loading, trucks then depart to the depot destination or customer location.

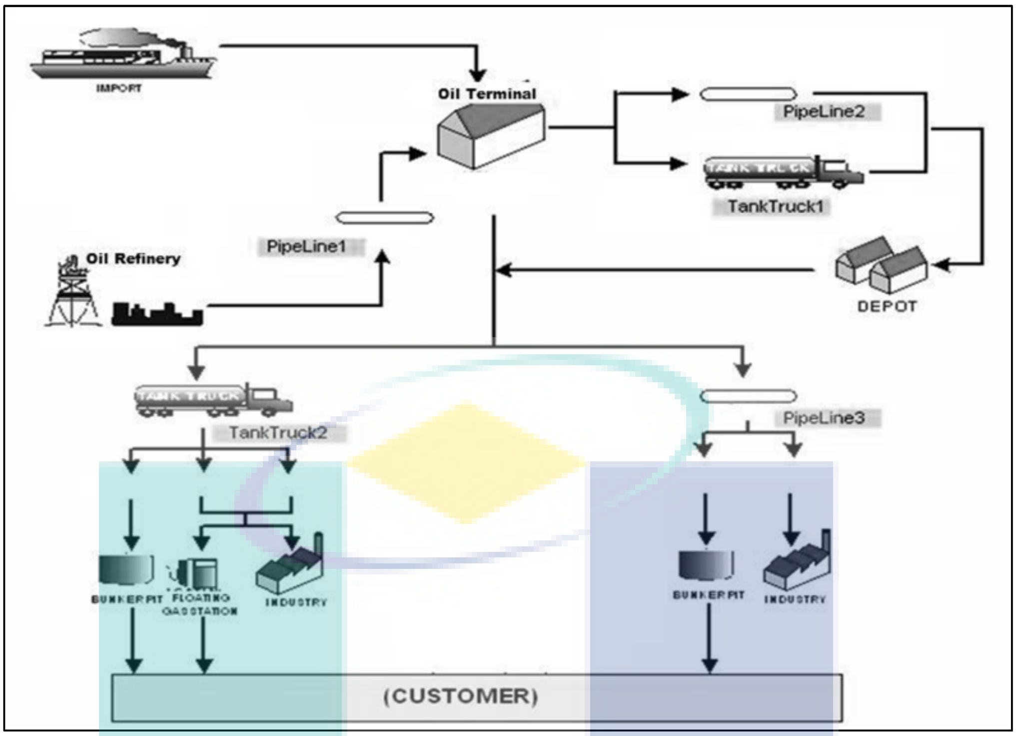


Figure 3.2: The process model flowchart for fuel oil distribution

On the other hand that the tanks in the terminal are full then the incoming import oil will be diverted downstream and sold as lower grade oil. This oil is not checked on its quality, and then is sold as *Discount Oil* which will be less profitable.

3.3 SIMULATION MODEL

Simulation provides many significant benefits and can facilitate problem solving process. Across a broad range of systems, it allows a modeler to diagnose problems, generate and experiment with new ideas, and identify the most complete solution (Musselman, 1992).The term simulation usually refers to the realization of an imitation of some larger, more complex system.

The simulation model developed in this study will be used to facilitate the operational analysis, by providing a computerized planning framework, which will provide rapid and complete analyses of alternative oil refinery plans. The proposed model allows the refinery management to evaluate various facility performances by simulating refinery operations.

Using a discrete-event simulation approach (Law and Kelton, 1991), a model of an oil refinery was created using ARENA software. ARENA supports hierarchical modeling, which is possible because of the ability to formally separate ARENA models into hierarchical views, called sub models. Each sub-model has its own full workspace for defining entity flow and displaying graphical animation. Sub models can contain any object supported in a model window (logic, static graphics, or animation) as illustrated in appendix B.

Figure 3.3 shows the detail of the simulation model created in ARENA. There are two entities used in the model, representing oil and trucks. In the model, an entity of oil is represented as a blue dot, whereas truck entities are identified by truck symbols. Both entities follow a static Poisson arrival process as depicted by the nature of the process, number of events that happen in an interval of time when the events are occurring at a constant rate. All inter-arrival times are independently and identically distributed exponential random variables with parameter as the average time between arrivals.

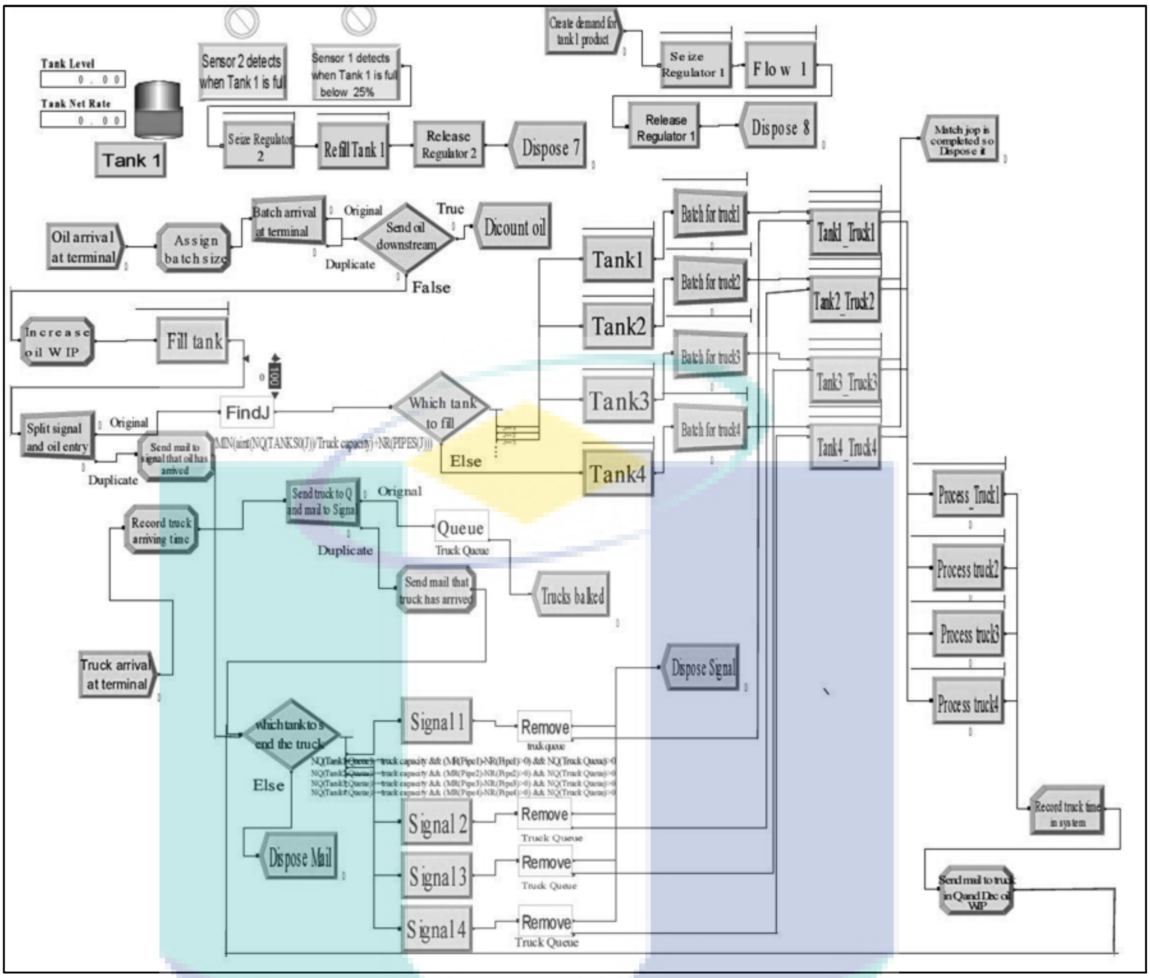


Figure 3.3: The oil transportation simulation model

The simulation model developed has twelve distinct modules, and each module is discussed below.

i. Oil arrival into the tank's station.

Using the Create a module, an entity, representing a batch of oil, arrives at the storage tanks. The time between arrivals of oil batches is exponentially distributed with a mean of *Oil_TBA*. Using equal probability, the Assign a module identifies (or tags) the *Batch Size* as small, medium or large.

ii. Decision point - should oil enter the tanks station?

The oil batch (small, medium or large) now arrives at a decision point, where it is determined whether or not each oil entity should enter the tank's station. A Decide module is used to evaluate the decision criteria; if the oil work in process is greater than or equal to the tanks' capacity, then the oil arrivals are sent downstream to be converted into a lower grade fuel, otherwise, the oil entities enter the tank's station. Once the oil enters, oil work in process is incremented by the number of oil entities that have entered the tanks station.

iii. The Sensor module.

Define a detection device that monitors the level of oil in a tank (Tank module). A sensor's location is specified using the Tank Name (tank1) and Level/Percentage prompts.

iv. The inventory tank module.

The Capacity is the maximum quantity that may be stored in the tank. The Initial Level is the quantity in the tank at the beginning of the simulation or when the system is cleared.

v. Tank fills time.

The oil entity enters a Process module to represent the time required to fill an entity of oil into a tank. Each entity in the batch is processed for an amount of time equal to the *Tank Fill Time*.

vi. Choice of a tank to fill.

A *FindJ* module conducts a search over an index from the start of the range to the end of the range to find the value of a global variable *J* that satisfies the search condition. The index chosen here is the *Number of Tanks* within the system. The search condition is:

MIN (aint(NQ(TANKS(J))/Truck capacity) + NR(PIPES(J))), which is used to send oil entities to that tank with the smallest number of truck batches waiting to be loaded. A Hold module is used to store the oil entities in each tank. A Duplicate module is then used to send an entity to check whether or not the oil should be released to a truck in the queue. The checkpoint is a Decision module where it is evaluated to see if there is enough oil (equal to a *Truck Capacity*) in the tank, at least one truck in the queue and that one tank is available for refueling.

vii. Arrival of a truck.

Using a Create a module, truck entities are generated one at a time with the time between arrivals being exponentially distributed with mean of *Truck_TBA*. Arriving trucks stay in a central queue, with queue length equal to the *Number* *of Tanks*. This ensures that queue length is a proportion to the tank's number and eliminates the need for another factor that can contribute to the oil refinery profitability.

viii. Send a truck to tank.

A decision module is used to determine if a truck in the central queue should be sent to a specific tank for refueling. The evaluation criterion is that if there is a truck in the queue and if a tank j (where, j = 1, ..., 4 tanks) has enough oil to fill the *Truck Capacity* and if the corresponding resource pipe i (where, i = 1, ..., 4 pipes) is not busy then, a truck is sent to tank/ The actual release of a truck from the queue is accomplished through the Remove module. After the decision to send a truck to a specific tank is made, the oil release mechanism is triggered through a Signal module. A signal is then sent to the Hold module, where the oil is being stored, to release oil equal to the *Truck Capacity*.

ix. Matching and batching.

After a signal is sent to the hold module to release oil equal to the *Truck Capacity*, a Batch module is used to batch (equal a *Truck Capacity*) the oil released from the Hold module. A Match module is then used to match one batch of oil to the truck just released from the central queue. This commences the refueling process at tank j.

x. Fill oil in a truck.

The matched oil batch and truck now enter a Process module to reflect the actual filling of oil into the truck, using a pipe, i and tank j, with process time equal to *Truck Fill Time*.

xi. Truck departure and balking.

A truck could depart from the refinery in one of two ways; depart to the customer site after refueling or balk from tank's station to the truck depot because the central truck queue is full. If trucks leave after refueling, a signal is sent to let the system know that a specific tank is now free and a truck can be allocated to this tank.

xii. Measure of performance and animation.

The total profit calculation is conducted using the expression feature of ARENA. Indicators (e.g. clock) and animations (e.g. pipe busy symbol) are used to verify design intent.

3.4 DATA COLLECTION

After the system has been flow-charted and organized, related information about the system operating and control logic are collected. Operation characteristics, such as average time between arrival of a batch of oil at the tanks station (*Oil_TBA*) and average time between arrivals of trucks at the refinery (*Truck_TBA*), are collected for each element in the system. Operational assumptions are also established for system elements when actual data are in short supply or non-existent. System elements are assumed to operate in a certain manner for the purposes of the simulation model. The assumptions need to be documented and modeled correctly.

Input data to the simulation model can be represented in a probability distribution. A probability distribution is a set of values that relate to an event occurring or likely to occur. There are several standard probability distributions that are frequently used in simulation studies, such as exponential, Gamma, Normal, Weibull, Beta, Uniform, Triangular, Lognormal and Erlang distributions. ARENA Input Analyzer has included the facility to find this standard distribution for a given empirical data.

The data can be collected in various ways. The data is not only useful for model development but also important for model validation. A comprehensive study of the oil refinery operations and refinery planning requires a rigorous data analysis. This analysis is essential to improve the system performance, and will reveal how the refinery resources and equipment are being utilized. Also, the study will assess the future needs of the refinery to run efficiently. Section 3.6 will explain the process and sources of data collection for the AL-Dura refinery terminal (ADRT) simulation study.

3.4.1 AL-Dura Refinery Terminal (ADRT) Data Collection

There are several reasons for collecting statistical and other data related to the ports. The traditional one is to show the role of the refinery within the national economy. This appears in the amount of investment expenditure; the number of trucks visiting the refinery and their capacities; the volume of goods loaded and discharged, classified by main group of commodities; the number of workers engaged in the oil refinery; and so on.

In many refineries, the statistical function is still limited to the traditional aggregates, which are published only for general information. Many of the data are only of a descriptive nature, which are less useful to the top management.

Statistical and other data are used as tools for improving refinery terminal operations. The management wishes to compare, on a continuous basis, the actual system activity with its potential. The data collected for this purpose should provide an intimate understanding of the functioning of the refinery terminal. This is essential, in order that the necessary decisions for increasing the efficiency of the current system can be taken.

For management purposes, certain efficiency indicators are needed, such as occupancy rate, average time spent by trucks at the refinery terminal, average waiting time of trucks, average number of trucks at the refinery terminal, *Number of Tanks* and tanks capacity required the quantity of incoming oil at the refinery terminal and actual number in the refinery terminal.

Another purpose of collecting information and presenting it in a systematic form is to provide an appropriate basis for developing the current system. The problem of choosing the right number of the level for each factor to develop the system is therefore of crucial importance, because a mistake may have a strong negative influence for a very long time to come. Hence the need for having adequate and accurate information, since this forms a real basis for any decision making.

Several methods and procedures were adopted in this research for data collection. These include the ADRT daily activity records, system observations, interviews, and a variety of published papers in different journals.

3.4.2 Daily Activity Record

The main data collections were from the historical record of daily activities of trucks movements at the refinery terminal. The terminal records the details of each truck that enters the refinery, and the attributes for each truck are also recorded.

These attributes include weight of the truck, truck type (35 m^3 or 40 m^3), truck speed (Mile), truck cost ($/Mile), loading and unloading time (minutes/truck), number of export and import oil carrying by trucks, as well as the type of trucks: Full tanks capacity.

3.4.3 System Observations

Although the recorded data from the daily activity sheets are quite detailed, observations of the activities at the oil terminal were however also made to verify the recorded (or missing) data. Observations were also made at the oil transport operations, where the truck carried the oil from the refinery to be sending to the depots, and vice versa.

3.4.4 Interviews

An interview with the responsible personnel at the oil refinery was also conducted. At the initial stage of the research, the interview was conducted with the Operational Research Manager of ADRT, in order to define problems and bottlenecks, and to improve the different activities at the refinery. Another interview was also conducted with the transportation manager to get a closer view of the oil transportation operations. The interviews provided a layout for the objective of the study.

3.4.5 Annual Reports

Data were also collected by CD’s, such as the ADRT daily loading and unloading report, which summarizes certain operations at the refinery terminal for the years 2006,2007. Many of the reports are also available through the Internet.

3.5 INPUT PARAMETERS

The simulation model contains variables, constants, and counters (Table 3.1). The logic behind choosing a particular value for the variables and constants are discussed below.

Tank fills time, which is the time required to fill 20 m^3 of oil into a tank, is set equal to 15 minutes. If this study consider the simple case of constant inter arrival times and *Batch Size*, then every 300 minutes an average batch of eight oil entities arrives at the tanks station. To facilitate the adequate flow into the tanks by preventing the *Tank Fill Time* from becoming a bottleneck in the system, *Tank Fill Time* of less than 37.5 (= 300/8) minutes should be set. Approximately. The *Tank Fill Time* was set around half this threshold limit. Truck fills time, which is the time required to fill 40 m^3 of oil into a truck, is set equal to 75 minutes. This number was provided by the case study (Oil Company). Compared to the *Tank Fill Time*, the *Truck Fill Time* is a higher number. Intuitively, it makes sense, as it should take less time to fill the same volume in a tank than a truck. Large, but fixed pipe structures fill oil into the tanks, whereas smaller, but removable pipes will be used for trucks so that it is easier manageable for truck drivers to connect the pipes to their trucks.

Large pipes should be able to carry more volume per minute than smaller pipes. Furthermore, with these constant inter arrival times and *Batch Size*, every 52.5 (= 37.5 + 15) minutes a tank is filled with an oil entity. The time required to fill oil equal to the *Truck Capacity* (40 m^3) into a tank equals 105 (=52.5 x 2) minutes. To prevent *Truck Fill Time* from becoming a bottleneck in the system, *Truck Fill Time* less than 105 minutes was chosen.

Table 3.1: Simulation model variable definition

	Purpose	Initial value(s)
Tank fill time	Time required to fill 20 m^3 of oil into a tank	15 minutes
Truck fill time	Time required to fill 40 m^3 of oil into a truck	75 minutes
Batch size	Oil entities arrive at the storage tanks in 3 batch sizes; small, medium and large	Small: 120 m^3Medium: 160 m^3 Large: 200 m^3
Truck capacity	The maximum volume of oil that a truck can hold	40 m^3
storage tanks capacity	The maximum volume of oil that the storage tanks can hold - derived as a product of *Number of Tanks* and *Tank Capacity*	(48,000-288,000) m^3
Oil_TBA	Average time between arrival of a batch of oil at the tank station	300 minutes
Oil WIP	Counter to track the total oil entities within the storage tanks system	0
Truck WIP	Counter to track the total truck entities within the tanks station system	0
Queue capacity	The number of truck(s) the central truck queue can hold	From 1 to 4
Truck cost per minute	The cost per minute charge for a truck	1
Cost per truck per trip	The cost charged per truck per trip. This is same as the cost per truck that balks out of the refinery	\$618 (see Table 5.11)
Lease cost	The cost per minute incurred to maintain the oil refinery facility	\$0.01
Regular oil CM	The contribution margin derived from the sale of 1 m^3 of regular oil	\$250
Discount oil CM	The contribution margin derived from the sale of 1 m^3 of discount oil	\$45
Tank Capacity	The maximum volume (1,000 m^3) of oil that a tank can hold	See Table 3.2
Truck_TBA	Average time between arrival of trucks at the refinery	See Table 3.2
Number of tanks	Number of storage tanks in the refinery	See Table 3.2

The case study showed that oil arrives at storage tanks in one of three batches; 120 m^3, 160 m^3 and 200 m^3. Each batch has an equal (1/3) probability of arrival. The study also indicated that each truck could carry up to 40 m^3 of oil. A truck will not leave the refinery until it is refueled to its capacity.

Refinery capacity is the maximum volume (1,000 m^3) of oil that the storage tanks can hold and is derived from the product of the two factor-levels; the *Number of Tanks* and the associated *Tank Capacity*. The capacity ranges from 48,000 m^3 to 288,000 m^3 based on the levels chosen for the two-factors, the *Number of Tanks* and *Tank Capacity*.

The case provided the incoming oil arrival rate. The oil time between arrivals (TBA) was derived by taking the reciprocal of this oil arrival rate. *Oil WIP* and *Truck WIP* are counters used to monitor the oil and truck work in process respectively within the system.

The *Queue Capacity*, which is the number of trucks the central truck queue can hold, is set equal to the *Number of Tanks* within the refinery. The logic behind setting up the *Queue Capacity* is that the *Queue Capacity* should be a proportion to the system size. Higher *Number of Tanks* would require long *Queue Capacity* and vice versa. Additionally, by setting up the *Queue Capacity* equal to the levels of the factor, *Number of Tanks*, the need for another key factor (*Queue Capacity*) that could impact oil refinery profitability, is removed, which simplifies the simulation model and analysis.

Truck Cost per Minute is estimated from collecting the data that it costs $10 per Miles to lease a truck and a driver. It is assumed that the trip from refinery to the depot for two ways depends on the distance between the refinery and the depots. The cost per truck per trip is thus set at $618 (see Table 5.11). The least cost per one cubic meter per tank per week is set ($100.8) to about half the contribution margin ($250) derived from the sale of the regular oil. The contribution margin per one cubic meter of regular and *Discount Oil* is about $250 and $45 respectively. The three-factors and four levels chosen for this study are summarized in table 3.2.

Table 3.2: Factors - level definition

Factors	Levels			
	1	2	3	4
Truck _TBA (minutes)	55	75	95	115
Tank Capacity (in 1,000 m^3)	48	56	64	72
Number of tanks	1	2	3	4

Truck_TBA levels were carefully chosen to ensure highest profitability per week could be achieved. Using highest and lowest tanks capacity, experiments were run to determine the highest average total profit per week by varying the *Truck_TBA*. The graphs of the analysis are shown in figures 3.4 and 3.5.

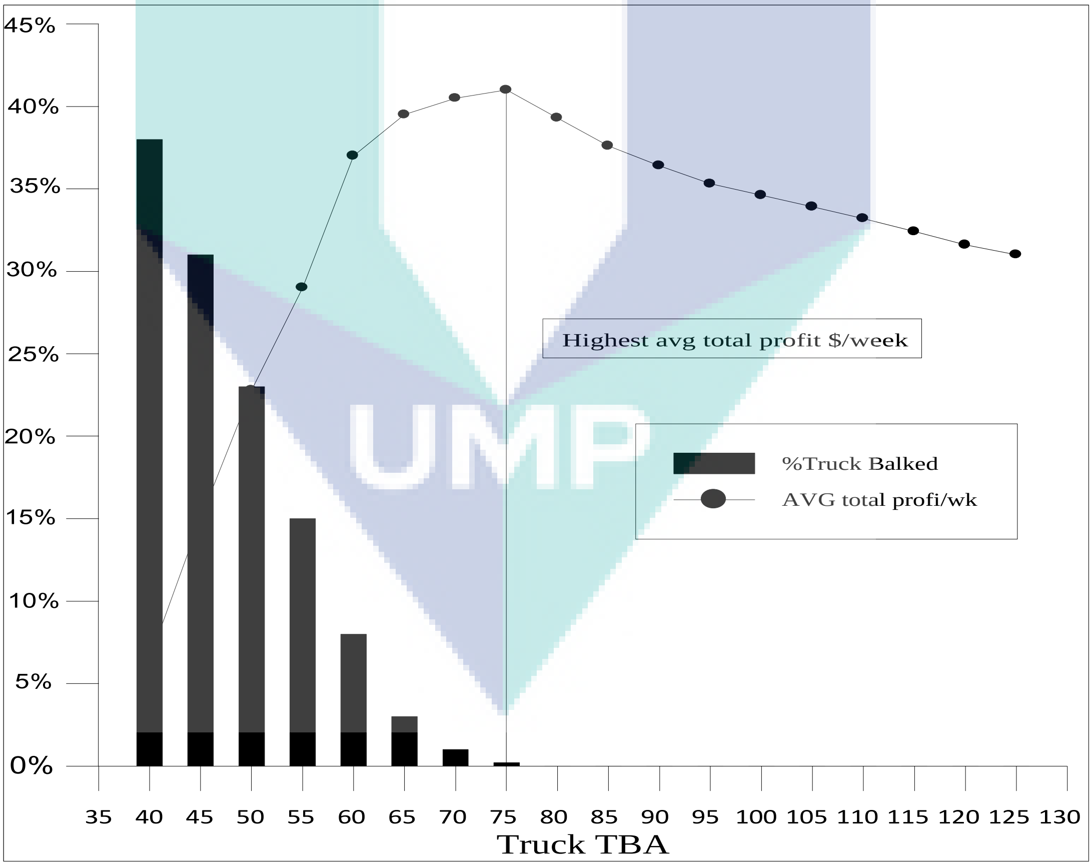


Figure 3.4: *Truck_TBA* analysis - highest tanks capacity

For highest storage tanks capacity (288,000 m^3), figure 3.4 shows that the highest average total profit per week occurs at *Truck_TBA* of 75 minutes. Additionally, the % truck balked, which is the percent of truck arrivals that balk out of the system, is close to zero. Therefore, *Truck_TBA* of 75 minutes was chosen as one of the levels for this factor.

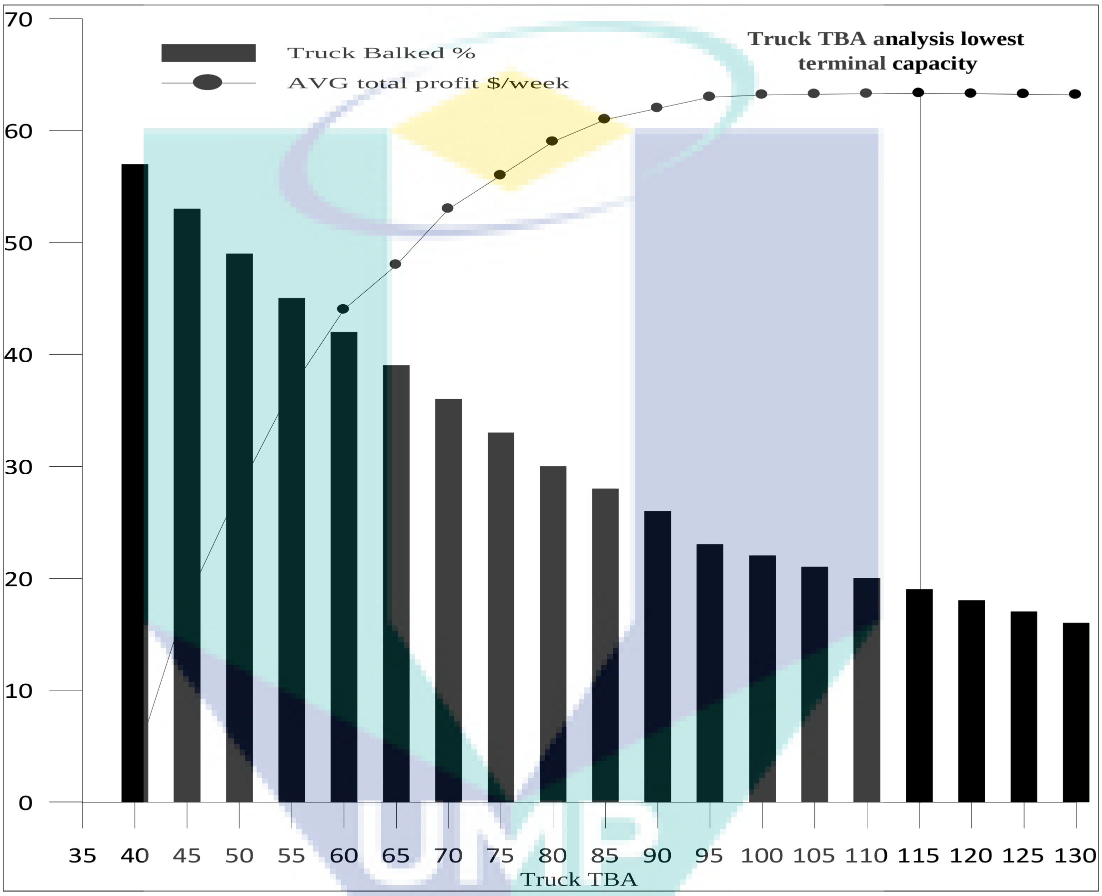


Figure 3.5: *Truck_TBA* analysis - lowest tanks capacity

3.5.1 Cost and Revenue Structure

The logic behind choosing the specific cost and contribution margin structure was discussed earlier under the variable and constant definition section. Tables 3.3 and 3.4 show a summary of the cost and contribution structure. Equation 3.1 summarizes the profit model.

Table 3.3: Cost structure

Cost	*Incoming oil costs($)/1, 000 m ^{3} =*		185
Truck costs($)	$/40 m^3	*Lease cost($)/tank/week/1,000 m ^{3}*	
Usage cost or cost/trip ($)	618	Small	4,838
Hourly rate ($)	60	Medium	5,645
Per minute rate ($)	1.0	Large	6,451
Balk cost to return empty ($)	618	Extra Large	7,258

Table 3.4: Revenue Structure

Revenue factors	**$/ m^3**
Discount Oil	200
Regular oil	385

The main profit equation

$$P = R - C \tag{3.1}$$

Where

P: Total Profit.

R: Total contribution margin from sale of regular and discount oil.

C: Total cost (Truck usage cost, Truck balk cost, Truck cost and lease cost).

3.5.2 Scope of the Study

Assumptions are statements that the study identifies to be facts. The following assumptions are made in the study.

i. The company had indicated that there is variability in the time between arrivals for trucks and oil at the refinery Also, truck and oil arrive randomly at the refinery in discrete batches. To satisfy the random discrete arrivals required for the experiment, the study will assume that the truck and oil arrival rates at the refinery will follow the Poisson process.

ii. The capacity of the truck, which is the maximum oil that a truck can carry, is assumed to be fixed. This is a reasonable assumption as trucks have fixed maximum carrying capacity.

iii. To economically justify the trip from the refinery to the depots, trucks will leave the loading area when completely filled to capacity.

iv. Trucks are the only transport vehicles available. For the scope of this thesis, this assumption is valid. Further research could be conducted to explore how different vehicles with different arrival rates and carrying capacity may impact oil refinery profitability.

v. Trucks arriving to the tanks station will be sequenced on a First-Come-First-Serve (FCFS) basis. This assumption allows the trucks to queue in the central queue in the order of their arrival. Trucks arriving at a later time will be processed based on their arrival sequence.

vi. The refinery and trucks operate 24 hours per day, 7 days per week, and 52 weeks per year. This assumption allows the simulation to mimic a real-life continuous oil refinery operation.

The following are the limitations of this study:

i. Pipeline and truck downtime are unknown and are assumed trivial for the study's purpose.

ii. The flow through the pipeline is constant. Different pipelines could have different flow rates, but the data is unavailable.

iii. Truck balk logic could be improved by allowing trucks to enter the tanks station and remain in the queue only if there is no enough oil in the tanks to fill the *Truck Capacity*. Due to modeling complications truck balk logic was solely based on the queue length, which is equal to the *Number of Tanks*.

For the purpose of this study the failed oil batches are considered trivial in their contribution to the oil refinery profitability. Another key implication of the quality test was the time it takes to test the oil batch. Since this time is approximately constant, it is assumed that the delay due to quality test is outside the oil refinery system. The following are the delimitations of this study:

i. Due to the limited scope of this study, at most four tanks will be used for simulation modeling. The expectation this *Number of Tanks* should provide enough information to set up the oil refinery profitability model. This delimitation statement is validated with the results to understand if more than four tanks have an impact on the oil refinery profitability model.

ii. Only trucks are used as transport vehicles. For the stated purpose of this study, it is enough to have one transport vehicle as changing to different vehicles may only have a small impact on oil refinery profitability.

3.6 MODEL TEST PROCEDURES

This section explains the test procedures involved in the model such as model validation and verification, calculating the number of runs required and setting up variance reduction methods to achieve a certain confidence interval and finally, addressing the initial transient problem in the non-terminating simulation model.

3.6.1 Simulation Validation and Verification

Model verification ensures that the model behaves in the way it is intended. Therefore the input data should be correct. Model validation ensures that the model has successfully captured the operational characteristics of the system and behaves the same as the actual system.

In order to verify the input data, one should check all the data entered into the model and make sure they are the same as the actual data. The unit used in the model should be consistent. If the model is developed in a modular system, then it is necessary to verify each of these modules. After these modules are put together to form a complete model, then it is also necessary to verify this complete model. The use of animation can be very helpful for model verification.

All elements of the system need to be validated to ensure that the proper effect and representation are correct. If there is an actual system that is being modeled, the computer model can be validated against the actual system and actual data. When the system does not exist, the model will be validated according to the actual data. The basic rule of thumb is that the model behaves as expected.

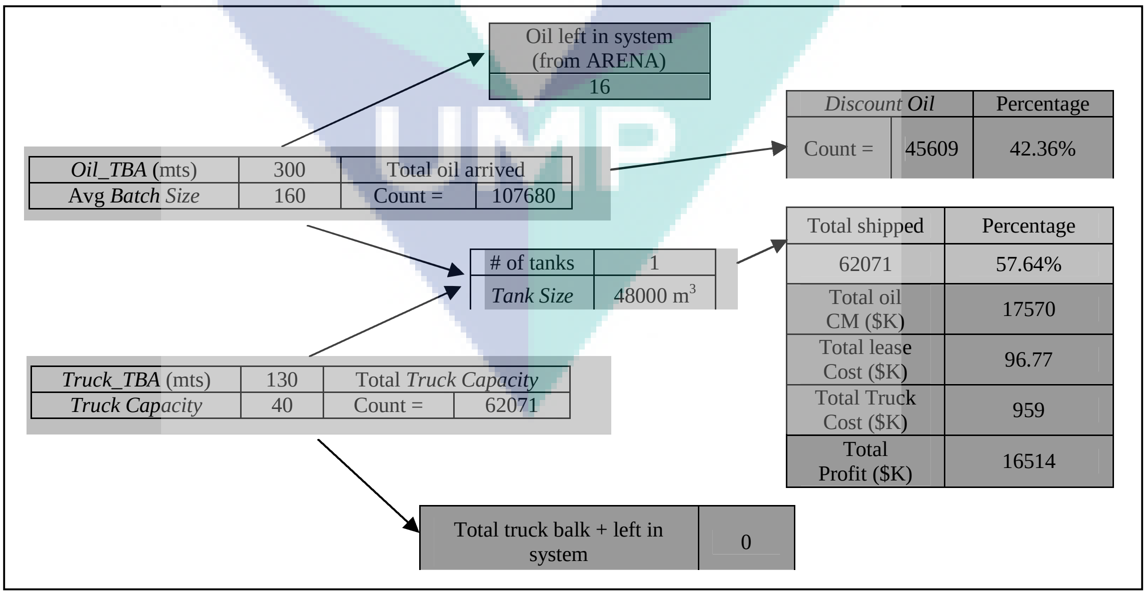
3.6.1.1 Verification

Verification is a technique used to determine if the simulation model performs according to design intent, more colloquially known as debugging of the model. Two experiments are discussed below (experiment 1 and experiment 2) as follows:

i. *Verification Experiment 1*

All input parameters were reset to a constant to reduce variability in the system so that verification can be easily accomplished. The model was run for 20 weeks with one replication. One tank with 48,000 m^3 capacities was used. *Truck_TBA* was set to 130 minutes. Tank and *Truck Fill Times* were set to 0. Hand calculations were compared with simulation output - results are summarized in table 3.5.

Table 3.5: Verification - Experiment # 1



SIMULATION RUN (Arena)

Replication	Trucks balked	Disc oil Shipped	Reg oil Shipped	Total oil arrived	Truck left in sys	Avg Truck TIS	Oil left in sys	Total Profit ($K)
1	0	45804	62031	107835	0	0	16	16515

Assuming that the average *Batch Size* is 160, the total volume of oil entities arriving in a week at the tanks station is:

$$((Totaltime(20weeks))/(Oil\_TBA)) \times AvgBatchSize + BatchArrivalatTime0$$
$$= 107{,}680\ m^3$$

The total number of *Truck Capacity* (amount of oil that can be taken away by trucks) arriving in a week at the refinery is:

$$((Totaltime(20weeks))/(Truck\_TBA)) \times TruckCapacity + TruckArrivalatTime0 \times TruckCapacity$$
$$= 62{,}071\ m^3$$

= Total *Regular Oil* shipped, assuming no trucks balked or are left in system at the end of simulation.

The total *Discount Oil* shipped = Total oil arrival - Total *Regular Oil* shipped - Total oil left in the system at end of simulation (this number got from simulation model in ARENA)

$$= 45{,}609\ m^3$$

Using the profit model:

Total oil contribution margin (CM) =

$$\text{Total } Regular\ Oil \text{ shipped } \times Regular\ Oil\ CM + \text{Total } Discount\ Oil \text{ shipped } \times Discount$$
$$= \$17{,}570K$$

Total *Lease Cost* =

$$Lease\ Cost \text{ per minute per tank per } 1{,}000\ \text{m}^3 \times 1 \text{ tank} \times Tank\ Capacity \times 20 \text{ weeks}$$
$$= \$96{,}768K$$

Total truck cost =

$$(Truck\ Cost\ per\ Minute)$$
$$\times\ (\text{Avg. truck time in system, which is obtained through simulation model in ARENA})$$
$$+\ (\text{Cost per truck per trip})\ \times\ (\text{Total trucks shipped}$$
$$+\ \text{Total trucks balked, which is obtained through simulation model in ARENA})$$
$$=\ \$959K$$

From equation (3.1):

$$Total\ Profit\ (P) = \$16{,}514K$$

Using the simulation (ARENA) output, Total profit = \$16,515K. This result is close to the one derived through the hand calculation. Other output data from simulation is also available under the Simulation Run (ARENA) section of table 3.5. The small error is due to randomness within the simulation model.

ii. Verification Experiment 2

Set oil and truck arrival rate to constants. Run the simulation for 20 weeks with 10 weeks for *Warm up Period*. Factor-levels used are: 4 tanks, *Tank Capacity* of 50,000 m^3 and *Truck_TBA* of 75 minutes. Set up trace and highlight module option to following simulation steps.

a. At time 0, one truck arrived and Truck In time was set to 0. The next arrival time was set at 106.9 minutes. Truck, with rank 1, was sent to Queue. Message was sent to Message Decision point to verify if there is enough oil in a tank for this truck. Since no oil is available in tanks, truck remains in Queue. Oil arrives at the storage tanks and next arrival time is set to 35.11 minutes. With 1/3 probability, *Batch Size* is set to 10(each one 20 m^3). Each entity within the batch is evaluated to see if *Oil WIP*≥(*Number of Tanks* * *Tank Capacity*). Since result of the evaluation is false, all of the 10 entities within the batch are sent to the process module, representing filling of tank. Every instant an oil entity passes through the Assign module, *OIL WIP* is increased by 1. Process module delays the oil entities, imitating filling a tank at a rate of 15 minutes per entity. Process queue has 9 entities with one entity currently being processed (by resource refinery Pipeline) for 15 minutes.

b. At time 15, one oil entity is sent from the process module to the FindJ module. J is set to 1, indicating that tank 1 should be filled. A duplicate entity is sent to Message Decision point to verify if this entity increases the cumulative oil in Hold module 1 (tank 1) equal to the *Truck Capacity* so that the queued truck could be sent to the tank. In this case, there is not enough oil to send the truck to the tank.

c. At time 30, another entity is released from the process module and is sent to FindJ module. J is set to 1 because there is one truck waiting in the queue and it will be more efficient to send this oil entity to tank 1 even though, other tanks have the least amount of oil. A duplicate entity is sent to Message Decision point to verify if this entity increases the cumulative oil in Hold module 1 (tank 1) equal to the *Truck Capacity* so that the queued truck could be sent to the tank. In this case, there is enough oil to send the truck to tank 1 therefore, the message continues through the Signal module to release oil (equal to *Truck Capacity*) from tank 1 and then the message goes to the Remove module, which removes one truck from the central queue. Batch module batches the two oil entities in tank 1. The Match module takes one batched oil entity and one truck entity and completes the match and then this matched entity then enters the Process module and seizes pipe l resource, depicting the filling of the truck at tank 1. This entity is now delayed for 75 minutes, which is the *Truck Fill Time*.

d. At time 35.11, oil arrives at storage tanks and next arrival time is set to 134.26 minutes. With 1/3 probability, *Batch Size* is set to 10. Each entity within the batch is evaluated to see if *Oil WIP*≥(*Number of Tanks* * *Tank Capacity*). Since result of the evaluation is false, all of the 10 entities within the batch are sent to the process module, representing filling of tank. Every instant an oil entity passes through the Assign module, *Oil WIP* is increased by one. Process delay, imitating filling a tank at a rate of 15 minutes per entity, is delayed for 15 minutes.

e. At time 45, a third entity is released from the process module and is sent to tank 2, which has the least amount of oil. A duplicate entity is sent to Message Decision point to verify if there is any truck queued at the central queue. In this case, there are no trucks available.

In summary, using the above experimentation method, the model was verified to meet design intent.

3.6.1.2 Validation

Validation is an exercise to ensure that the model behaves as the real system by comparing the results obtained from the simulation runs to that of the actual or observed data from the real system. Unfortunately, for the purpose of this thesis, there is a real system to compare with the model results. However, it is possible to comment on whether or not the model output represents reality. The AL Dura and Biji refineries and eight depots were taken for this study. One such attempt is on the choice of refinery capacity. Tank farm example illustrates an example in which a tank farm consists of four tanks of capacity 48,000 m^3, two tanks of capacity 56,000 m^3, 3 tanks of capacity 64,000 m^3 and 4 tanks of capacity 72,000 m^3. This is in the range of this study's choice of *Number of Tanks* and *Tank Capacity*, which yields a tanks station capacity in the range of 48,000 m^3 to 288,000 m^3. Additionally, certain parameter values such as *Truck Capacity* and oil in flow rate have been obtained from the case study. Furthermore, the cost and revenue parameter values have been obtained from AL Dura refinery. The model is verified as per design intent and that the design model was developed from the real system, it is reasonable to assume that the model is validated to a real case study.

3.6.2 Variance Reduction Technique

There are 64 different alternatives being compared and the goal of this study is to understand the differences between these alternatives with respect to average total profit per week. These differences are measures of the effect of changing from one alternative to another. It makes sense to simulate all of these alternatives under conditions that are as similar as possible, except for the factor-level change. To reduce variance associated with the output from this stochastic simulation model, a variance reduction technique was applied which is called the Common Random Numbers (CRN) approach, in which the same random numbers were used across simulated alternatives. ARENA offers a smart and easy method to apply CRN to the simulation model, which contains three sources of randomness; two Poisson arrival processes (oil and truck arrivals) and one assign module with probabilistic (chance) determination of *Batch Size*.

Three separate streams of random numbers are used for the three sources of randomness. Stream 1 and 2 are used for the oil and truck arrivals respectively. Stream 3 is used for the assign module. By applying this variance reduction technique, the results would be more precise, providing narrower confidence intervals.

3.6.3 Estimating the Number of Runs Required

Using the methods described in Law and Kelton (1991), the number of runs required to estimate the average profit with a specified error or precision, is calculated as follows.

Choose a level of confidence, 100(1 - α) %, at which to estimate an expectation using the sample average. $\overline{\mathrm{X}}$. The relative error, γ, which is the allowable percentage of error in$\overline{\mathrm{X}}$, was arbitrarily chosen to be 0.1. If we construct a confidence interval for the mean on a fixed number of replications, N and this study assume that the estimates for population variance and mean will not change as the number of replications increases, and then an approximate expression for the number of replications is given by:

$$N(\gamma) = min\left\{ i \geq N\colon \frac{t_{i-1,1-\propto}\sqrt{\frac{S^2}{i}}}{|\bar{X}|} \leq \acute{\gamma} \right\} \tag{3.2}$$

Where

$\acute{\gamma} = \gamma/(1+\gamma)$ Is the adjusted relative error required to get an actual relative error of (γ). Since γ=0.05, we have:

$$\acute{\gamma} = (0.05) / (1+0.05) = 0.0476$$

3.7 RUN SCENARIOS

To start the estimation process, an initial run of 180 weeks with 20 weeks of warm-up period with ten replications were conducted for four different scenarios and the total profit week ($K) for each run was compiled in tables 3.6 - 3.9.

3.7.1. Scenario 1

Highest refinery capacity (four tanks, each with capacity of 72,000 m^3, for a total of 288,000 m^3) and highest truck arrival rate (*Truck_TBA* = 55 minutes).

Using $\gamma = 0.05$, $\acute{\gamma} = 0.0476$, $\overline{X} = 39.1126$, $S = 1.01851$ and $t_{10-1,\ 1-0.99} = 3.25$ for a 99% confidence level, equation (1) for scenario 1 becomes,

$$= 0.02652 < 0.0476$$

Therefore, 10 replications do meet the 99% confidence level and relative error of 0.05 requirements.

Table 3.6: Number of runs analysis - scenario 1

Number of Runs Calculation Relative Error, R = 0.05	**Highest tanks capacity and truck arrival rate**		
10 replications	Gamma, r = R/(R+1)	0.0476	
Runs	Total Profit/wk ($K)	*Truck_TBA* =55, *Tank Capacity* =72 and *Number of Tanks* =4	
1	38.3904		
2	38.9656		
3	39.2514		
4	37.4627		
5	38.9100		
6	39.3404		
7	38.8580		
8	39.4184		
9	39.0102		
10	41.5188		
Average	39.1126		
Std Dev	1.01851		
Student T Statistics, $t_{10-1,\ 1-0.99}$	3.24980		
$t_{10-1,1-0.99} \times \{[Sqrt(S^2/n)]/X(Avg)\}$	0.02652	<	0.0476

3.7.2. Scenario 2

Highest refinery capacity (four tanks, each with capacity of 72,000 m^3, for a total of 288,000 m^3) and lowest truck arrival rate (*Truck_TBA* = 115 minutes).

Using $\gamma = 0.05$, $\acute{\gamma} = 0.0476$, $\bar{X} = 113.3851$, $S = 4.6995$ and $t_{10-1,\ 1-0.99} = 3.25$ for a 99% confidence level, equation (1) for scenario 2 becomes,

$$= 0.01965 < 0.0476$$

Therefore, 10 replications do meet the 99% confidence level and relative error of 0.05 requirements.

Table 3.7: Number of runs analysis - scenario 2

Number of Runs Calculation	**Highest tanks capacity and lowest truck arrival rate**		
Relative Error, R = 0.05			
10 replications	Gamma, r =	0.0476	
Runs	Total Profit/wk	*Truck_TBA* =115, *Tank Capacity* =72 and *Number of Tanks* =4	
1	117.8543		
2	116.5629		
3	109.4674		
4	108.9219		
5	116.4812		
6	119.5465		
7	104.8064		
8	111.1040		
9	113.0782		
10	116.0285		
Average	113.3851		
Std Dev	4.6995		
Student T Statistics, $t_{10-1,\ 1-0.99}$	3.2498		
$t_{10-1,1-0.99} \times \{[Sqrt(S^2/n)]/X(Avg)\}$	0.01965	<	0.047

3.7.3. Scenario 3

Lowest refinery capacity (one tank, with capacity of 48,000 m^3) and highest truck arrival rate (*Truck_ TBA* 55 minutes).

Using $\gamma = 0.05$, $\acute{\gamma} = 0.0476$, $\bar{X} = 237.23$, $S = 4.797$ and $t_{10-1,\ 1-0.99} = 3.25$ for a 99% confidence level, equation (1) for scenario 3 becomes,

$$= 0.009488 < 0.0476$$

Therefore, 10 replications do meet the 99% confidence level and relative error of 0.05 requirements.

Table 3.8: Number of runs analysis - scenario 3

Number of Runs Calculation Relative Error, R = 0.05	**Lowest tanks capacity and highest truck arrival rate**		
10 replications	Gamma, r = R/(R+1)	0.0476	
Runs	Total Profit/wk ($K)	*Truck_TBA* =55, *Tank Capacity* =48 and *Number of Tanks* =1	
1	243.016		
2	237.319		
3	227.533		
4	241.257		
5	242.637		
6	239.498		
7	234.911		
8	233.133		
9	238.251		
10	234.818		
Average	237.237		
Std Dev	4.797		
Student T Statistics, $t_{10-1,\ 1-0.99}$	3.2498		
$t_{10-1,1-0.99} \times \{[Sqrt(S^2/n)]/X(Avg)\}$	0.009488	<	0.0476

3.7.4. Scenario 4

Lowest refinery capacity (one tank, with capacity of 48,000 m^3) and lowest truck arrival rate (*Truck_TBA* = 115 minutes).

Using $\gamma = 0.05$, $\acute{\gamma} = 0.0476$, $\bar{X} = 449.674$, $S = 3.1101$ and $t_{10-1,\ 1-0.99} = 3.25$ for a 99% confidence level, equation (1) for scenario 4 becomes,

$$= 0.004030 < 0.0476$$

Therefore, 10 replications do meet the 99% confidence level and relative error of 0.05 requirements.

Table 3.9: Number of runs analysis - scenario 4

Number of Runs Calculation	**Lowest tanks capacity and truck arrival rate**		
Relative Error, R = 0.05			
10 replications	Gamma, r = R/(R+1)	0.0476	
Runs	Total Profit/wk ($K)	*Truck_TBA* =115, *Tank Capacity* =48 and *Number of Tanks* =1	
1	451.567		
2	450.120		
3	448.067		
4	449.767		
5	448.739		
6	454.796		
7	447.355		
8	448.658		
9	453.619		
10	444.052		
Average	449.674		
Std Dev	3.1101		
Student T Statistics, $t_{10-1,\ 1-0.99}$	3.2498		
$t_{10-1,1-0.99} \times \{[Sqrt(S^2/n)]/X(Avg)\}$	0.004030	<	0.0476

3.8 SUMMARY

The purpose of this chapter is to give an overview of the simulation modeling process which could be used as a management decision support tool to help in evaluating and improving the comprehensive oil terminal operations. The chapter aims at developing understanding and assessing of the different steps in a simulation process. The scope of the study of the simulation model and the model variable definitions are captured, and then use verification and validation to determine if the simulation model performs according to design intent, more colloquially known as debugging of the model.

CHAPTER 4

MODEL EXPERIMENTATION

4.1 INTRODUCTION

Model experimentation is a process of experimenting on the developed models. In chapter 3, the model was developing to imitate the system under study. Furthermore the model was also verified and validated to reflect the real system.

In this chapter, the model is used to experiment various parameters that contribute to the behavior of the system under study. Many alternatives that are to be simulated must be determined in advanced before the model is experimented. Often, the decision concerning which alternatives to simulate may be a function of runs that have been completed (Thesen and Travis, 1992). The Design of Experiment (DOE) provides the desired information to achieve the aims and objectives. DOE also provides a structure for the modeler's learning process (Maria, 1997 and Kelton et al, 1998). Using DOE can also determine how system parameters can be compared in order to analyze the system.

In this chapter this study describes the hypothesis and the experimentation for multifactor analysis of variance and Tukey procedures required to determine the best combination of factor levels. Model experiment is also used to understand which factors and their interactions that are significant to profit maximization.

4.2 HYPOTHESIS AND EXPERIMENT APPROACH

In this study, the hypothesis is that three factors namely *Tank Capacity*, *Number of Tanks* and *Truck Arrival Rate* contribute to the profit for the oil refinery operations. The intent is to find that combination that optimizes the oil terminal to yield the highest average total profit per week and also to examine the effects of the three-factors and their interactions on profitability. The initial step involved conducting a three-factor (with four levels) analysis of the variance experiments to locate the best mix of *Tank Capacity*, *Number of Tanks* and *Truck Arrival Rate* to obtain the highest profit.

4.3 MULTIFACTOR ANALYSIS OF VARIANCE

A multifactor single analysis of variance (ANOVA) was performed on three-factors each with four levels to identify the best combination of factor levels that will yield the highest profit. The three-factors in this analysis are: *Truck_TBA*, *Tank Capacity* and *Number of Tanks*. The number of levels of these three-factors will be denoted by i, j, and k and L_{ijk} is the number of observations made with factor *Truck_TBA* at level i, factor *Tank Capacity* at level j and factor *Number of Tanks* at level k. Note that all $L_{ijk} = L = 10$ replications.

The model is

$$X_{ijkl} = \mu_{ijk} + \varepsilon_{ijkl}$$

Where,

I, *j*, *k* = 1, 2, 3, 4 (levels); L = 1, ..., 10 (replications) and

$$\mu_{ijk} = \mu + \propto_i + \beta_j + \delta_k + \gamma_{ij}^{AB} + \gamma_{ij}^{AC} + \gamma_{jk}^{BC} + \gamma_{ijk}$$

The ε_{ijkl} are assumed independent, normally distributed, with mean 0 and variance σ^2.

4.4 HYPOTHESIS DEFINITION

Main effect and interaction hypotheses are tested by forming *F* ratios with the mean squared error (MSE) in each denominator (see Table 4.1).

Table 4.1: Multifactor ANOVA - hypothesis definition

Null hypothesis	**Test statistics**	**Rejection region**
H_{0A} / H_{0B} / H_{oc} All α_i's = β_j's = δ_k's = 0	f_A = MS(A)/MSE f_B = MS(B)/MSE f_C = MS(C)/MSE	$f_A > F_{\alpha,i-1,ijk(l-1)}$ $f_B > F_{\alpha,j-1,ijk(l-1)}$ $f_C > F_{\alpha,k-1,ijk(l-1)}$
H_{0AB} / H_{0AC} / H_{oBc} Al lγ_{ij}^{AB}'s = γ_{jk}^{AC}'s = γ_{jk}^{BC}'s = 0	f_{AB} = MS (AB)/MSE f_{AC} = MS (AC)/MSE f_{BC} = MS (BC)/MSE	$f_{AB} > F_{\alpha,(i-1)*(j-1),ijk(l-1)}$ $f_{AC} > F_{\alpha,(i-1)*(k-1),ijk(l-1)}$ $f_{BC} > F_{\alpha,(k-1)*(j-1),ijk(l-1)}$
H_{0ABC} : All γ_{ijk}'s = 0	f_{ABC} = MS (BC)/MSE	$f_{ABC} > F_{\alpha,(i-1)*(k-1)*(j-1),ijk(l-1)}$
Alternative Hypothesis	At least two α_i's, β_j's, δ_k's, lγ_{ij}^{AB}'s, γ_{jk}^{AC}'s, γ_{jk}^{BC}'s or γ_{ijk}'sare different	

Note: For the purpose of table 4.1 illustration, A represents the factor, *Number of Tanks*, B represents the factor, *Tank Capacity* and C represents the factor, *Truck_TBA*.

Detailed analysis is shown in Appendix A, and Table 4.2 summarizes the multifactor ANOVA results. For each of the individual factors, using a significance level of 0.01, the p-value is close to zero; therefore, H_0 is rejected in favor of the hypothesis that the individual factor effect is significant. For each of the two-factor interaction effects, using a significance level of 0.01, the p-value is close to zero; thus H_0 is rejected in favor of the hypothesis that the two-factor interaction effect is significant. Finally, for the three-factor interaction, using a significance level of 0.01, the p-value is close to zero; therefore, H_0 is rejected in favor of the hypothesis that the three-factor interaction effect is significant.

Table 4.2: Multifactor ANOVA results

Source	SS	df	MS	f	P-level
Number of Tanks	462856.3	3	154285.4	1725.39	0
Truck_TBA	425051.8	3	141683.9	1584.47	0
Tank Capacity	259134.7	3	86378.24	965.98	0
Truck_TBA&Number of Tanks	158300.9	9	17588.99	196.79	0
Truck_TBA and *Tank Capacity*	129395.8	9	14377.32	160.78	0
Tank Capacity&Number of	14866.45	9	1651.83	18.47	0
All factors	3400.4	27	125.94	1.41	0
Error	2414.35	576	89.42		
Total	1455421	639			

To get a better understanding of the multifactor ANOVA results, attention is drawn upon the graphical illustrations in figures 4.1 through 4.7. These illustrations indicate how average total profit per week changes as these factor-levels increase or decrease. Also, insight can be gained on how the two-factor and three-factor interactions significantly impact average profit per week.

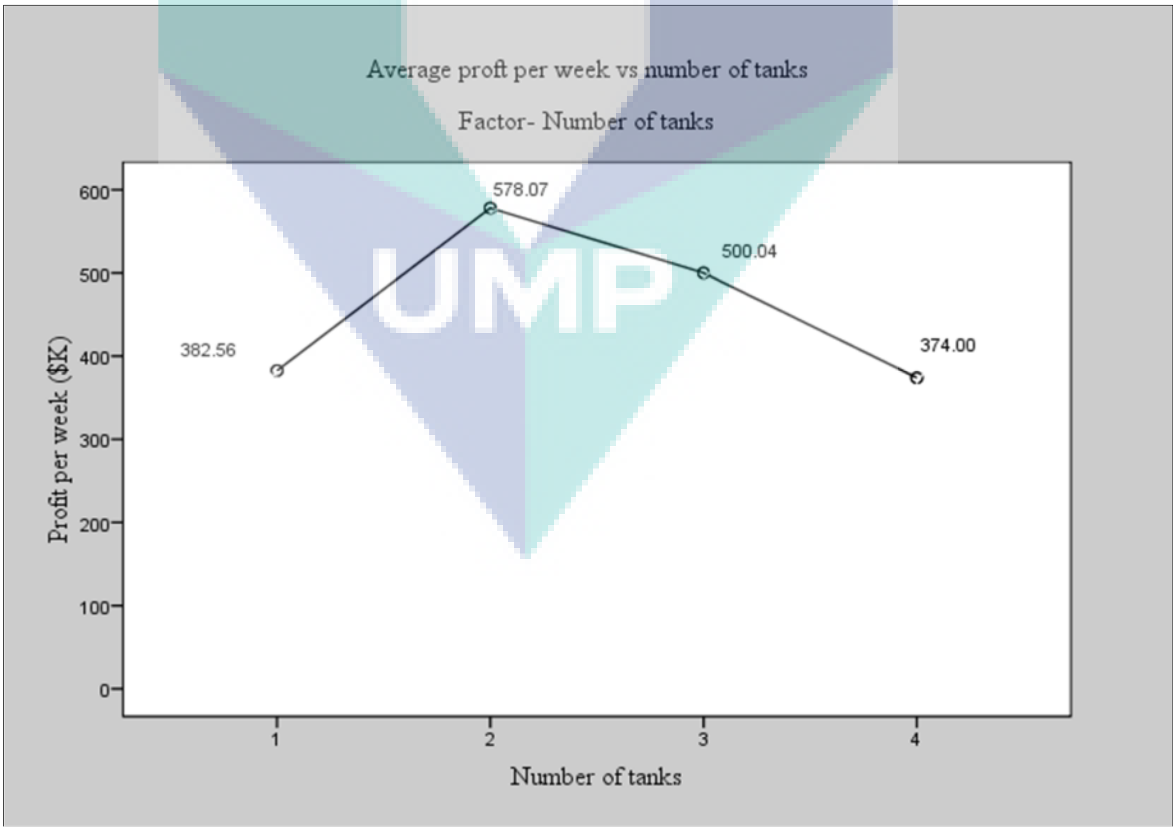


Figure 4.1: One factor effect - *Number of Tanks*

Figure 4.1 shows the relationship between the main effect *Number of Tanks* and average total profit per week ($K). Since the factor *Number of Tanks* significantly impacts average total profit per week, at least one of the four average total profits per week significantly differs from the others. It appears from the graph that average total profit per week increases from 1 to 2 tanks and then decreases as *Number of Tanks* increases. Two tanks appear to yield the best average total profit per week.

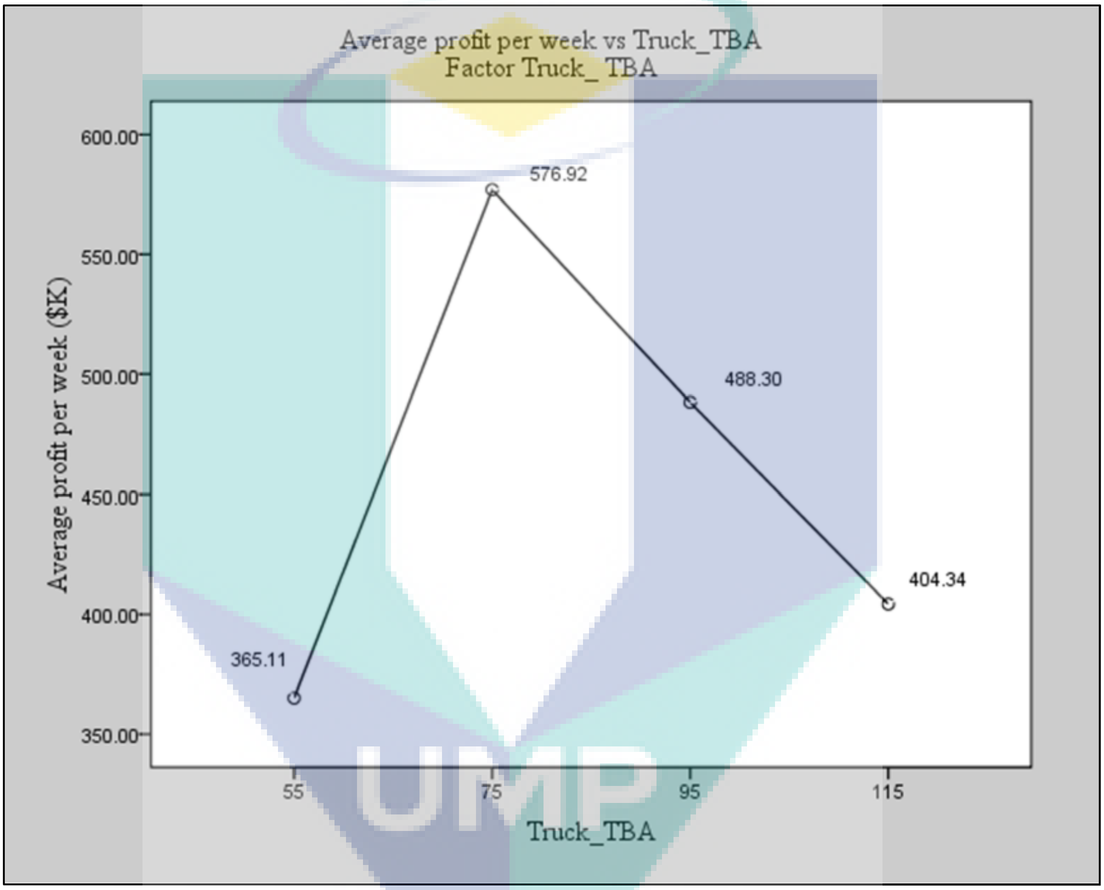


Figure 4.2: One factor effect - *Truck_TBA*

Figure 4.2 shows the relationship between the main effect *Truck_TBA* and average total profit per week ($K). Since the factor *Truck_TBA* significantly impacts average total profit per week, at least one of the four average total profits per week significantly differs from the others. It appears from the graph that average total profit per week increases from *Truck_TBA* of 55 minutes to 75 minutes and then decreases as *Truck_TBA* increases. *Truck_TBA* of 75 minutes appears to yield the best average total profit per week.

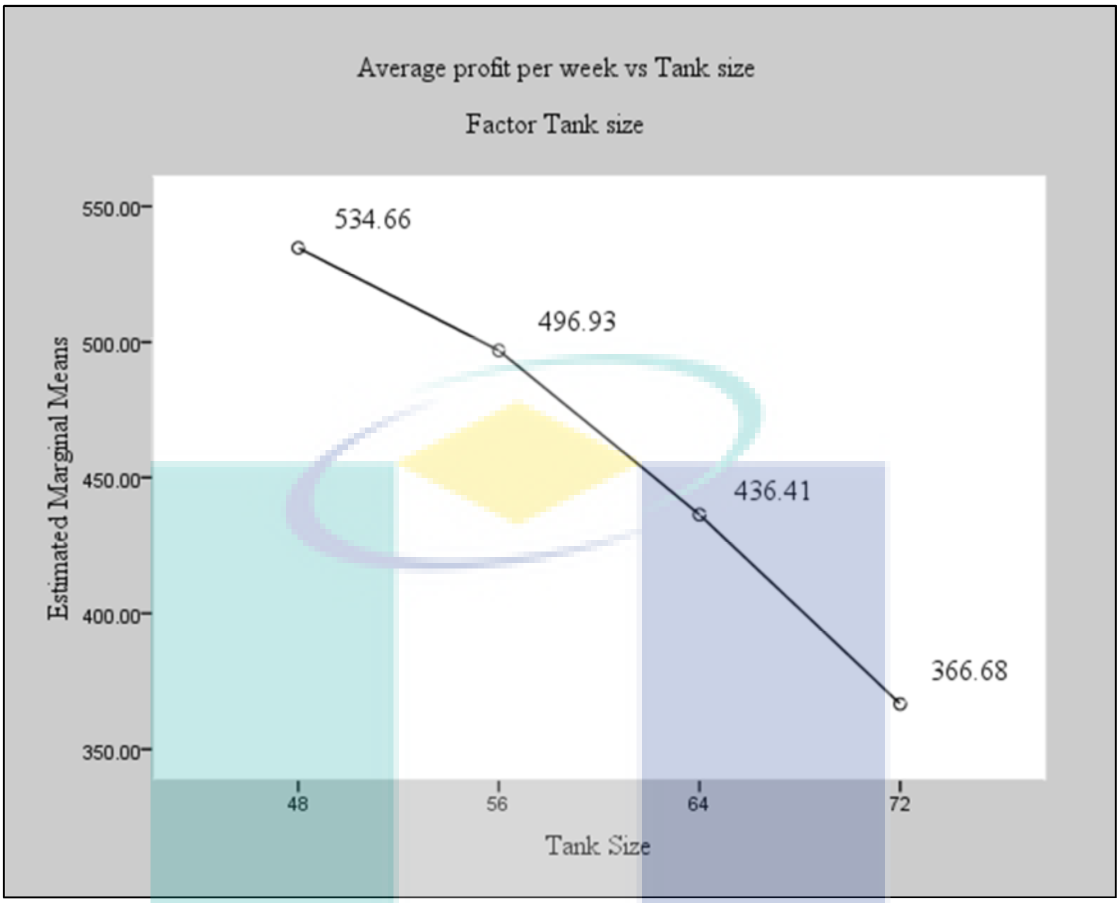


Figure 4.3: One factor effect - *Tank Capacity*

Figure 4.3 shows the relationship between the main effect *Tank Capacity* and average total profit per week ($K). Since the factor *Tank Capacity* significantly impacts average total profit per week, at least one of the four average total profits per week significantly differs from the others. It appears from the graph that average total profit per week decreases as *Tank Capacity* increases. *Tank Capacity* of 48,000 m^3 appears to yield the best average total profit per week.

Figure 4.4 shows the relationship between average total profit per week and the two-factor interaction effect between *Number of Tanks* and *Truck_TBA*. For tanks 2 through 4, it appears that *Truck_TBA* of 75 minutes is the best solution. Average total profit per week increases as *Truck_TBA* increases from 55 minutes to 75 minutes, after which, average total profit per week decreases as *Truck_TBA* increases. For 1 tank, average total profit per week appears to be the highest for *Truck_TBA* of 95 minutes.

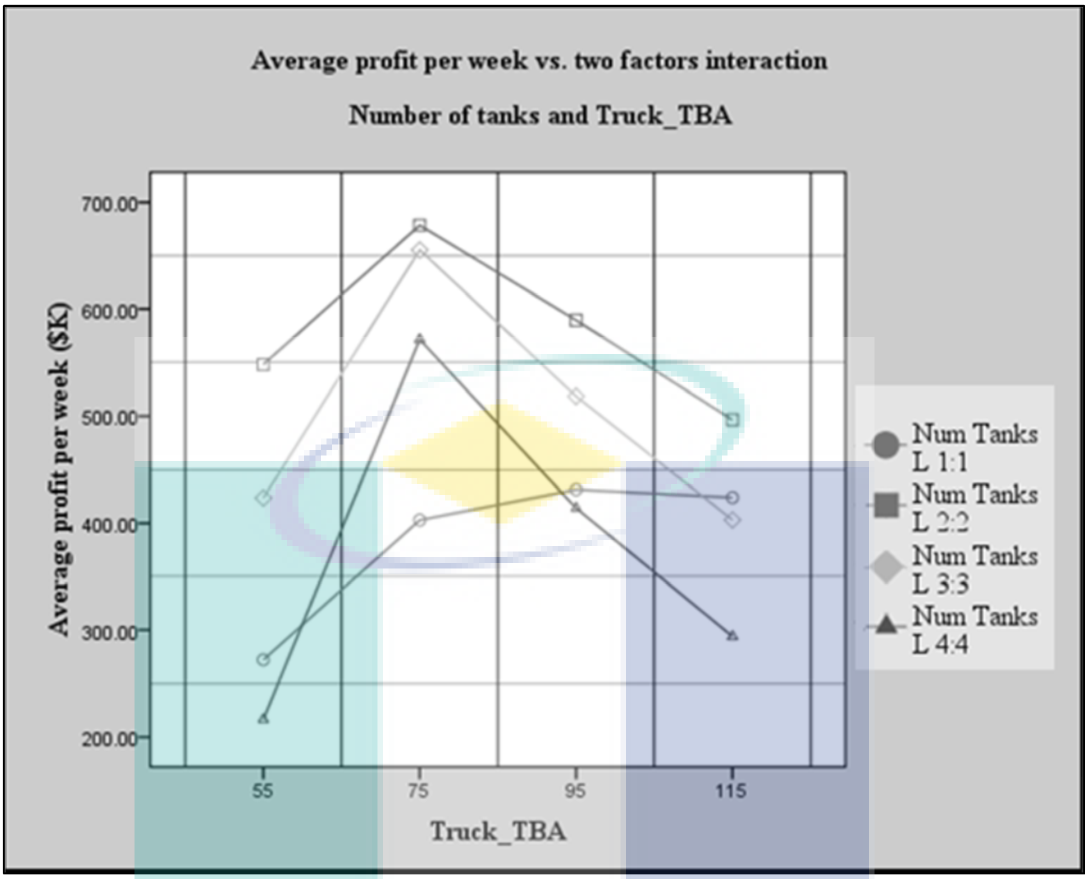


Figure 4.4: Two factors interaction - *Number of Tanks* and *Truck_TBA*

The existence of an interaction effect between *Number of Tanks* and *Truck_TBA* means that the difference in average total profit for different levels of *Number of Tanks* does depend on the level of the factor *Truck_TBA*. In other words the difference in average total profit for two levels of factor *Number of Tanks* is not the same for all levels of the factor *Truck_TBA*.

Figure 4.5 shows the relationship between average total profit per week and the two-factor interaction effect between *Number of Tanks* and *Tank Capacity*. For tanks 2 through 4, it appears that average total profit per week decreases as *Tank Capacity* increases. For 1 tank, average total profit per week appears constant for different values of *Tank Capacity*. The existence of an interaction effect between *Number of Tanks* and *Tank Capacity* means that the difference in average total profit for different levels of *Number of Tanks* does depend on the level of the factor *Tank Capacity*. In other words the difference in average total profit for two levels of factor *Number of Tanks* is not the same for all levels of the factor *Tank Capacity*.

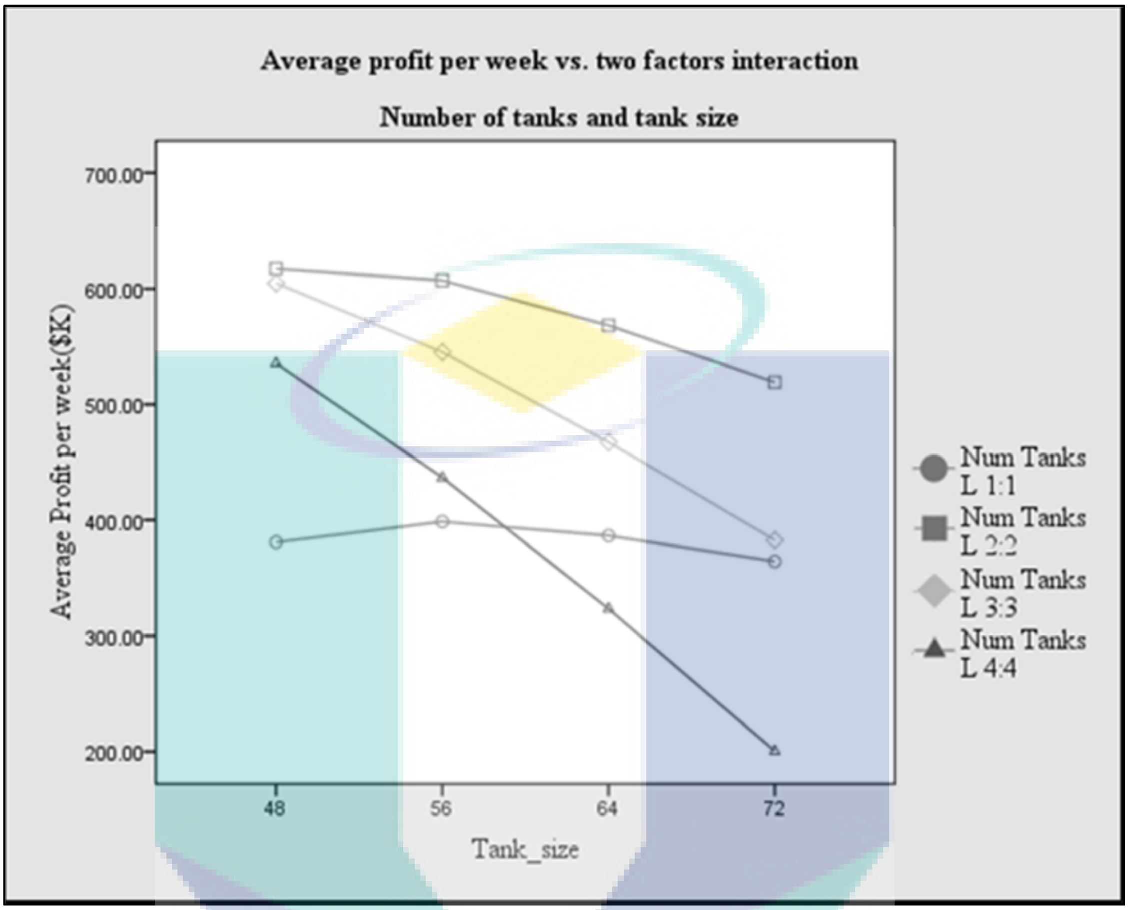


Figure 4.5: Two factor interaction - *Number of Tanks* and *Tank Capacity*

Figure 4.6 shows the relationship between average total profit per week and the two-factor interaction effect between *Truck_TBA* and *Tank Capacity*. It appears that average total profit per week decreases as *Tank Capacity* increases. The existence of an interaction effect between *Truck_TBA* and *Tank Capacity* means that the difference in average total profit for different levels of *Truck_TBA* does depend on the level of the factor *Tank Capacity*. In other words the difference in average total profit for two levels of factor *Truck_TBA* is not the same for all levels of the factor *Tank Capacity*.

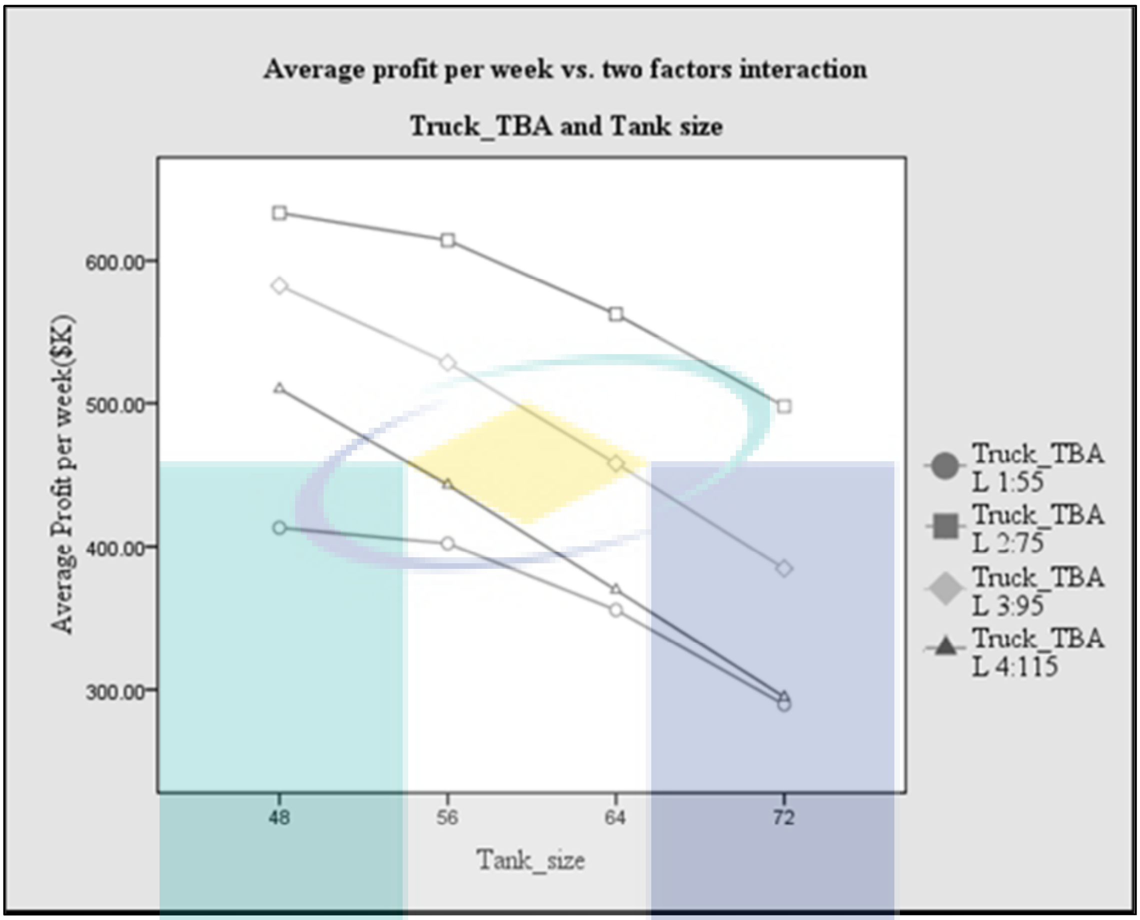


Figure 4.6: Two factor interaction - *Truck_TBA* and *Tank Capacity*

Figure 4.7 shows the relationship between average total profit per week and the three factor interaction effect between *Number of Tanks*, *Truck_TBA* and *Tank Capacity*. It appears from the graph that average total profit per week decreases as *Tank Capacity* increases. The three way interaction effect is described as the difference between the average two-factor interaction effect of *Truck_TBA* and *Tank Capacity* when *Number of Tanks* is at one level (1 tank) and the average two-factor interaction effect of *Truck_TBA* and *Tank Capacity* when *Number of Tanks* is at another level (2 tanks) .

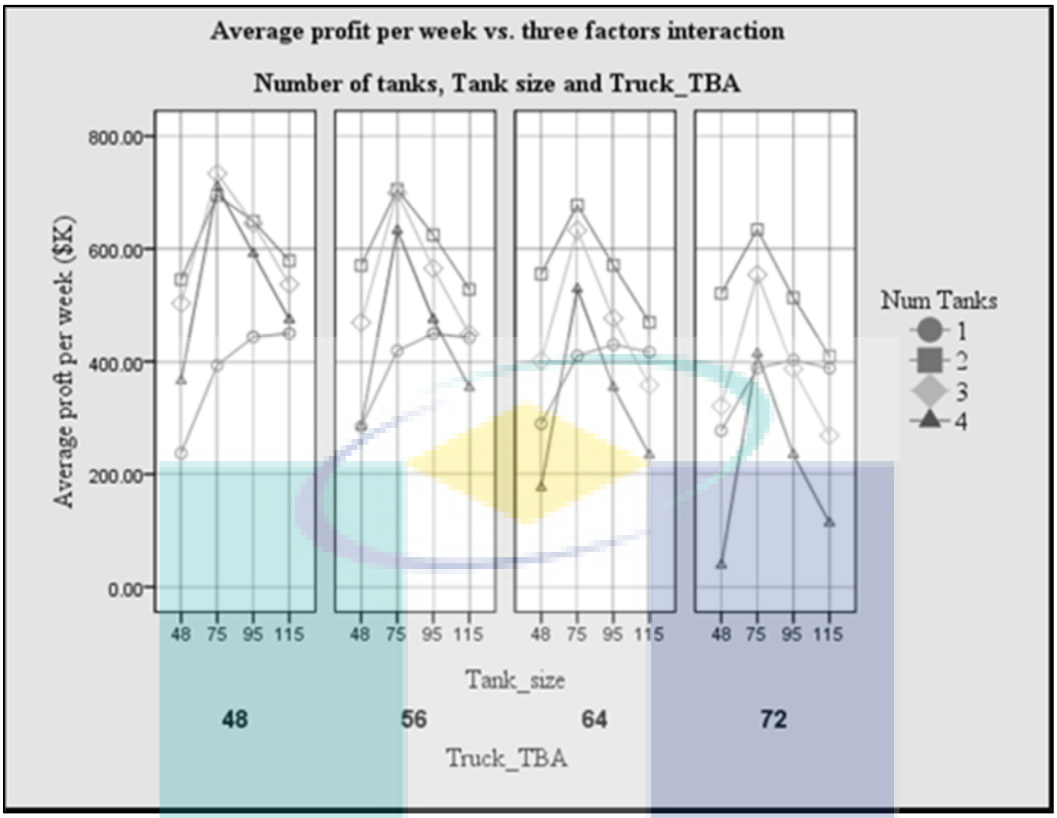


Figure 4.7: Multi factors interaction - *Truck_TBA*, *Tank Capacity* and *Number of Tanks*

Now that we understand which factors and their interactions are significant, it is time to identify which combination of *Tank Capacity*, *Number of Tanks* and *Truck_TBA*yields the highest profit. To resolve this, Tukey's procedure (Devore, 1995) is applied.

4.5 TUKEY'S METHOD OF IDENTIFYING SIGNIFICANTLY DIFFERENT MEANS

This procedure is applied to test whether or not there does exist a combination of *Tank Capacity*, *Truck_TBA* and *Number of Tanks* for which the mean (across ten replications) profit per week is statistically higher than other factor-level mix for the factor under study (see appendix A). It should be noted that only those factors and their interactions for which H_0 has been rejected (Multifactor 4 level ANOVA) would undergo the Tukey's procedure. Tukey's procedure is described below:

Using$\propto$, find $Q_{\alpha,m,v}$from the Studentized range distribution table

i. Where $\propto$, is the significance level (0.01)

ii. m = number of levels being compared; 4 treatment means are compared in case of comparison by each factor,16 treatment means are compared in case of two-factor interaction effect (for example, *Truck_TBA* and *Tank Capacity*) and 64 treatment means are compared in case of three-factor interaction effect.

iii. v = degrees of freedom for error = 576

Determine $w = \mathrm{Q}_{\propto,\mathrm{m},\mathrm{v}} * \sqrt{(\mathrm{MSE}/h)}$

Where MSE = Mean Square Error

h= number of observations arranged to obtain each of the averages being compared; 160 observations are involved in case of comparison by each factor, 40 observations are involved in case of two-factor interaction (for example, *Truck_TBA* and *Tank Capacity)* and 10 observations are involved in case of three-factor interaction.

The sample means are listed in increasing order and those pairs that differ by greater than w are put in a new group. Any pair of sample means that is given a new group number corresponds to a pair of true levels that are significantly different from each other.

Since the null hypothesis was rejected for the individual factors, the two-factor interaction and the three-factor interactions, there will be seven separate Tukey's analyses conducted to identify significant differences in the factor-levels.There will be three values of w required for the seven analyses. The first value (Table 4.3) will be applied to the Tukey's analysis for the individual factors, the second value (see table 4.7) of w will be applied to the Tukey's analysis for the two-factor interaction and finally, the third value (see table 4.11) of w will be applied to the Tukey's analysis for the three-factor interaction.

Table 4.3: Tukey's procedure for one factor

Tukey's Procedure (for single factors)	
Significance level, $\propto=$	0.01
Number of levels being compared, $m =$	4
Number of Tanks factor levels, $I =$	4
Truck_TBA factor levels, $J =$	4
Tank Capacity factor levels, $K =$	4
Total number of observations per design point, $L =$	10
Degrees of freedom, $v = I * J * K * (L - 1) =$	576
$Q_{\propto,m,v} = Q_{0.01,4,576} =$	4.40
MSE (from Multifactor ANOVA) =	89.42
Number of observations arranged to compare averages, $h =$	160
$w = Q_{\propto,m,v} * Sqrt(MSE/h) = Q_{(0.01,4,576)} * (Sqrt(MSE/h)) =$	3.29
Number of statistically different groups identified =	4

The first analysis is conducted on the factor, *Truck_TBA*. Tukey's test procedure for factor (*Truck_TBA*) analysis is shown in table 4.4. Since the differences between successive averages, Delta, are greater than w (see table 4.7), there will be four distinctive groups of levels that are significantly different from each other. In summary, from this analysis, using a significance level of 0.01, it is evident that all four levels of the factor, *Truck_TBA* are significantly different from one another in their effect on average total profit per week. Notice that the choice of *Truck_TBA* of 75 minutes is determined to be the best level to reach highest profitability.

Table 4.4: Tukey's analysis summary for *Truck_TBA*

Truck TBA (mts)	Avg ($K) Profit/wk	Delta	Group
55	365.114	-	1
115	404.339	39.226	2
95	488.303	83.963	3
75	**576.920**	**88.618**	**4**

The second analysis is conducted on the factor, *Tank Capacity*. Tukey's test procedure for factor (*Tank Capacity*) analysis is shown in Table 4.5. Again, all the differences between successive averages, under the column "Delta", are greater than w, therefore there will be four distinctive groups of levels that are significantly different from each other. In summary, from this analysis, using a significance level of 0.01, it is evident that all four levels of the factor, *Tank Capacity* are significantly different from one another in their effect on average total profit per week. Again, notice that the choice of *Tank Capacity* of 48,000 m^3 is determined to be the best factor-level choice to attain highest average total profit per week. Furthermore, it appears that as *Tank Capacity* increases, average total profit per week decreases.

Table 4.5: Tukey’s analysis summary for *Tank Capacity*

Tank Capacity (1,000 m^3)	Avg ($K) Profit/wk	Delta	Group
72	366.679	-	1
64	436.410	69.731	2
56	496.927	60.517	3
48	**534.659**	**37.732**	**4**

The third analysis is conducted on the factor, *Number of Tanks*. Tukey's test procedure for factor (*Number of Tanks*) analysis is shown in table 4.6. Once more, all numbers under the column "Delta" is greater than w, thus there exists four distinctive groups of levels that are significantly different from each other. In summary, from this analysis, using a significance level of 0.01, it is evident that all four levels of the factor, *Number of Tanks* are significantly different from one another in their effect on average total profit per week.

The graphical illustration in figure 4.1 showed that the choice of 2 tanks yielded the highest average total profit per week. Tukey's analysis proves, using a 99% confidence level, that figure 4.1's statement is correct.

Table 4.6: Tukey’s analysis summary of *Number of Tanks*

Number of Tanks	Avg ($K) Profit/wk	Delta	Group
4	374.003	-	1
1	382.563	8.560	2
3	500.039	117.476	3
2	**578.070**	**78.031**	**4**

The second value of w is applied for Tukey's analysis conducted on the two-factor interactions. Tukey's test procedure for two-factor interactions is shown in table 4.7. Using a significance level of 0.01, all three two-factor interactions proved significant therefore, the fourth, fifth and sixth Tukey's analysis will focus on the two-factor interaction effects.

Table 4.7: Tukey's procedure for two-factors

Tukey's Procedure (for two-factors interaction)	
Significance level, $\propto =$	0.01
Number of levels being compared, $m =$	16
Degrees of freedom for error, $v =$	1856
$Q_{\propto,m,v} = Q_{0.01,16,576} =$	5.49
MSE (from Multifactor ANOVA) =	89.42
Number of observations arranged to compare averages, $h =$	40
$w = Q_{\propto,m,v} * Sqrt(MSE/h) = Q_{(0.01,16,576)} * (Sqrt(MSE/h)) =$	8.208

Table 4.8: Tukey's analysis on *Number of Tanks* and *Tank Capacity*

Number of tanks	*Tank Capacity* (1,000 m^3)	Avg ($K) profit/wk	Delta	Group
4	72	200.443	-	1
4	64	323.340	122.897	2
1	72	364.143	40.803	3
1	48	380.935	16.793	4
3	72	382.705	1.770	4
1	64	386.603	3.898	4
1	56	398.573	11.970	4
4	56	436.568	37.995	5
3	64	467.298	30.730	6
2	72	519.425	52.127	7
4	48	535.663	16.238	8
3	56	545.398	9.735	8
2	64	568.400	23.003	9
3	**48**	**604.758**	**36.358**	**10**
2	**56**	**607.173**	**2.415**	**10**
2	**48**	**617.283**	**10.110**	**10**

The fourth analysis is conducted on the two-factor interaction between *Number of Tanks* and *Tank Capacity* and the summary result shown in Table 4.8. Using a significance level of 0.01, the differences between successive averages, which are greater than w, are assigned a new group, resulting in a total of ten groups of combination of treatment means that are significantly different from each other. The factor-level mix that yields the highest average total profit per week are two tanks each with capacity 48,000 m^3 or 56,000 m^3 or three tanks each with capacity 56,000 m^3. The tanks station capacity range for this factor-level mix solution is between (48,000 m^3 * 2=) 96,000 m^3 to (48,000 m^3 * 3=) 144,000 m^3.

The fifth analysis is conducted on the two-factor interaction between *Number of Tanks* and *Truck_TBA* and the summary result shown in Table 4.9. Using a significance level of 0.01, the differences between successive averages, which are greater thanw, are assigned a new group, resulting in a total of eleven groups of combination of treatment means that are significantly different from each other. The factor-level mix that yields the highest average total profit per week is 2 tanks with *Truck_TBA* of 75 minutes. It should be noted that the results of the single factor analysis on *Number of Tanks* and *Truck_TBA* yielded level values equal 2 tanks and 75 minutes respectively.

Table 4.9: Tukey's analysis on *Number of Tanks* and *Truck_TBA*

Number of tanks	Truck TBA (mts)	Avg ($K) profit/wk	Delta	Group
4	55	216.620	-	1
1	55	272.138	55.518	2
4	115	293.940	21.803	3
1	75	402.823	108.882	4
3	115	403.018	0.195	4
4	95	414.035	11.018	4
3	55	423.610	9.575	4
1	115	423.978	0.368	4
1	95	431.315	7.337	4
2	115	496.423	65.108	5
3	95	518.405	21.983	6
2	55	548.088	29.683	7
4	75	571.418	23.330	8
2	95	589.455	18.038	9
3	75	655.125	65.670	10
2	**75**	**678.315**	**23.190**	**11**

Table 4.10: Tukey's analysis on *Tank Capacity* and *Truck_TBA*

Truck TBA (mts)	***Tank Capacity* (1,000 m^3)**	**Avg ($K) profit/wk**	**Delta**	**Group**
55	72	289.570	-	1
115	72	294.830	5.260	1
55	64	355.668	60.837	2
115	64	369.580	13.912	3
95	72	384.490	14.910	4
55	56	402.140	17.650	5
55	48	413.078	10.938	5
115	56	442.978	29.900	6
95	64	457.983	15.005	7
75	72	497.825	39.842	8
115	48	509.970	12.145	8
95	56	528.320	18.350	9
75	64	562.410	34.090	10
95	48	582.418	20.008	11
75	56	614.273	31.855	12
75	**48**	**633.173**	**18.900**	**13**

The sixth analysis is conducted on the two-factor interaction between *Tank Capacity* and *Truck_TBA* and the summary result shown in table 4.10. Using a significance level of 0.01, the differences between successive averages, which are greater thanw, are assigned a new group, resulting in a total of thirteen groups of combination of treatment means that are significantly different from each other. The factor-level mix that yields the highest average total profit per week is *Tank Capacity* of 48,000 m^3 with *Truck_TBA* of 75 minutes. It should be noted that the results of the single factor analysis on *Tank Capacity* and *Truck_TBA* yielded level values equal 48,000 m^3 and 75 minutes respectively.

The third value of w is applied for Tukey's analysis conducted on the three-factor interactions. Tukey's test procedure for three-factor interactions is shown in table 4.11. Using a significance level of 0.01, the three-factor interaction proved significant therefore, the seventh Tukey's analysis will focus on the three-factor interaction effect.

Table 4.11: Tukey's Procedure for Three-Factors

Tukey's Procedure (for three-factor interaction)	
Significance level, $\propto =$	0.01
Number of levels being compared, $m =$	64
Degrees of freedom for error, $v =$	1856
$Q_{\propto,m,v} = Q_{0.01,64,576} =$	5.65
MSE (from Multifactor ANOVA) =	89.42
Number of observations arranged to compare averages, $h =$	10
$w = Q_{(\propto,m,v)} * Sqrt(MSE/h) = Q_{(0.01,64,576)} * (Sqrt(MSE/h)) =$	16.895

The seventh analysis is conducted on the three-factor interaction between *Number of Tanks*, *Tank Capacity* and *Truck_TBA* and the summary result shown in table 4.12. Using a significance level of 0.01, the differences between successive averages, which are greater than w, are assigned a new group, resulting in a total of nine groups of combination of treatment means that are significantly different from each other. *Truck_TBA* of 75 minutes is the best choice of level. *Number of Tanks* range from 2 to 4 and *Tank Capacity* vary from 48,000 m^3 to 64,000 m^3.

Table 4.12: Tukey's analysis on Three-Factors

Number of Tanks	***Truck_TBA* (mts)**	***Tank Capacity* (1,000 m^3)**	**Avg ($K) Profit/WK**	**Delta**	**Group**
2	75	64	676.39	29.60	9
2	75	48	697.79	21.40	9
3	75	56	699.58	1.79	9
2	75	56	706.51	6.93	9
4	75	48	713.34	6.83	9
3	75	48	740.11	26.77	9

Table 4.13 provides more insight into the solution set. For the solution set, it appears that the percentage of regular oil shipped is between 78.7% and 86.2%. Consequently, the percentage of discount oil shipped is between 13.8% and 21.3%. The truck balk rate ranges from as low as 2.7% to as high as 9.3%. The truck balk cost as a percent of total cost varies between 0.69% and 4.12%. The truck cost is the major cost item when compared to the lease cost and ranges from 78.53% to 89.22%. The majority of the truck cost is due to truck trips and truck time spent within the system. Truck trip costs as a percentage of total costs range from 47.59% to 49.57%. Truck in system costs as a percentage of total costs varies between 31.11% and 37.57%.

Truck trips are necessary costs and cannot be avoided. However, truck wait cost in system (other than the time spent refueling) is an avoidable cost and occurs due to variability in the system. The average truck time in system is between 81.8 minutes and 96.24 minutes. Ideally the truck should spend 75 minutes for refueling and 0 minutes for waiting to be refueled. For example, in the case of 2 tanks with capacity of 64,000 m^3 and with *Truck_TBA* of 75 minutes, the average truck time in system is 87.42 minutes, which is 12.42 (= 87.42 - 75) minutes higher than the time required to refuel.

Table 4.13: Insight into solution set

Solution set (sorted by profit/week)	180 weeks run, 20 weeks warm up period and 10 runs					
Avg profit/week ($K)	676.39	697.79	699.58	706.51	713.34	740.11
Truck_TBA (minutes)	75	75	75	75	75	75
Number of Tanks	2	2	3	2	4	3
Tank Capacity (1,000 m^3)	64	48	56	56	48	48
Total Tanks capacity (1,000 m^3)	128	96	168	112	192	144
Avg. of total regular oil shipped (%)	84.10	78.70	84.60	83.20	86.20	84.50
Avg. of total discount oil shipped (%)	15.90	21.30	15.40	16.80	13.80	15.50
Avg. truck balk rate (%)	4.90	9.30	2.70	6.30	2.90	4.40
Avg. truck trip cost (% of total cost)	47.59	49.15	47.93	48.89	48.25	49.57
Avg. truck in system cost (% of total cost)	32.99	37.57	31.11	34.98	32.26	34.67
Avg. truck balk cost (% of total cost)	1.74	4.12	0.69	2.49	0.78	1.58
Avg. truck cost (% of total cost)	82.32	90.84	79.73	86.36	81.29	85.82
Avg. lease cost (% of total cost)	17.68	9.16	20.27	13.64	18.71	14.18
Avg truck time in system (minutes)	87.42	96.24	81.80	90.09	84.26	88.02

4.6 SUMMARY

By using the hypothesis that for a given average rate of inflow of oil and *Truck Arrival Rate* into the tanks station, and the associated cost and contribution margin structure, there is a combination of *Tank Capacity*, *Number of Tanks* and average *Truck Arrival Rate*, which yields the highest profitability for the oil refinery operations. A multifactor single analysis of variance (ANOVA) was performed on three-factors each with four levels to identify the best combination of factor levels that will yield the highest profit.

Tukey's method was used to test whether or not there does exist a combination of Tank Capacity, *Truck_TBA* and Number of Tanks for which the mean (across ten replications) profit per week is statistically higher than other factor-level mix for the factor under study.

CHAPTER 5

DEVELOPING A MATHEMATICAL MODEL

5.1 INTRODUCTION

Developing a model is a challenging task because the modular needs to understand the behavior or elements of the system being modeled. It can be thought of as an entity, which captures the essence of but without the presence of reality. A photograph is a model of reality portrayed in the picture. A mathematical equation is used to model the energy contained in a given material. Thus, a model captures some aspect of the reality it attempts to represent. In chapter 3 and 4, a simulation model was developed to imitate the system under study. Furthermore the model was also verified and validated. The model is also used to experiment to different factors that contribute profit differently to the system. In this chapter, a generic mathematical linear programming (LP) is developed using I-Log software with the aim to minimize total transportation distance and cost. The model also determines the optimal assignment from refineries to depots that is which refinery will send its oil to which depot and by how much. The next sections of this chapter discuss mathematical programming, developing the LP model, data collections and results and conclusion.

5.2 MATHEMATICAL MODEL

A mathematical model is an equation, inequality, or system of equations or inequalities, which represents certain aspects of the physical system being modeled. The mathematical expression, which describes the behavior of the measure of effectiveness, is called the objective function. Objective functions are written in mathematical expression containing variables, the value of which is to be determined. If the objective function is to describe the behavior of the measure of effectiveness, it must capture the relationship between that measure and those variables that cause it to vary. Therefore, in the objective function the decision maker needs to know the type of objective function, if the mathematical expression has the greatest possible value named maximization or the least possible numerical value named minimization.

All decision-making models can be classified as either deterministic models or probabilistic models. This depends on how influential the uncontrollable factors are in determining the outcome of a decision. Unlike deterministic models where good decision is judged by its outcome alone, in probabilistic models the decision maker is concerned with both the outcome value and the amount of risk each decision carries.

Optimization, also called mathematical programming, in general, deals with the problem of determining optimal allocation of limited resources to meet a given objective. The objective function must represent the goal of the decision maker. The resources may correspond to, for example, people, materials, money, or land. Out of permissible allocations of the resources, it is desired to find the one or ones that maximize or minimize some numerical quantity such as profit or cost.

LP deals with a class of programming problems which both the objective function to be optimized is linear and all relations among the variables correspond to resources, known as constraints, are linear. In any LP model the objective function must be linear. That means all variables have the power of 1, and they are added or subtracted, not divided or multiplied. The objective function represents the goal of the decision maker, must be either maximization or minimization. The constraints must also be linear. Moreover, the constraints must be closed, that is, they are expressed in the form of a system of equations or inequalities. More specifically they either have signs <=, >= or =.

Formulation of an LP model can be tedious and troublesome task. A wrong model can result because a wrong set of variables is included or some improper relationships among the variables are constructed. There are some guidelines in an effective model formulation. Any LP consists of four parts: a set of decision variables, the parameters, the objective function, and a set of constraints.

A minimization problem of an LP written in the matrix form is:

Minimize Z(**X**) = CX = $\sum_{j=1}^{n} C_j X_j$

Subject to **AX** = **B**

$\mathbf{X} \geq \mathbf{0}$

Where

A is an m$\times$n matrix that represent rows of coefficients of the constraints 1 to *m* each having *n* coefficients.

$X_1, ..., X_n$ are the column vector of decision variables.

C is the row vector or a $(1 \times n)$ matrix of coefficients of the objective function.

B is the parameters of the constraints, which is a $(n \times 1)$ matrix or a column vector.

A feasible solution numerical vector, X that satisfies all the constraints and sign restrictions. An optimum feasible solution (or an optimum solution) is a feasible solution that minimizes the objective function, Z(X) among all feasible solutions. Murthy (1983) has proved that if the above LP has a feasible solution, it has an optimum feasible solution if and only if X(y) $\geq$ 0 for every homogeneous solution y corresponding to that LP. Bernard Kolman (1993) proved that a homogeneous systems of m equations in n unknowns always has a nontrivial solution if m < n, that is, if the number of unknowns exceed the number of equations.

5.3 THE PROPOSED MODELS

The transportation of some oil related products that originate at a number of refineries to be sent to their appropriate destinations is to be modeled. The model depicts the shipments of the products from the origins to their destinations using trucks vehicles of fixed, known capacity. Given a refinery, to where and how much a specific product Benzene, kerosene or Diesel is to be sent. The limitation for the receiving end is it cannot save more than what it is capable of a capacity. The model is to find out how much Benzene, kerosene or Diesel from specific refinery to be sent to the respective destinations as illustrated in figure 5.1, so that the total transportation distance is minimized. The model is developed using LP method, results (average total transportation cost) will use in the simulation model to be one of the important parameters (see Table 3.1).

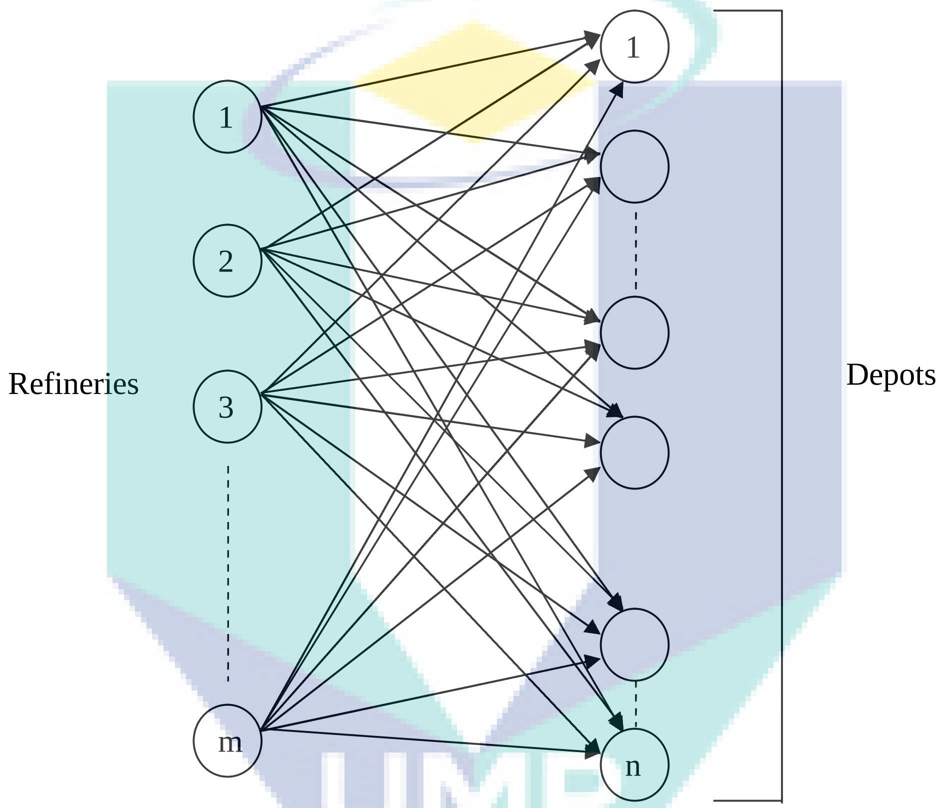


Figure 5.1: Transportation network between refineries and depots

5.3.1 Oil Productions to be transported

A set of refineries located at different areas where crude oil was found, each producing known amounts of oil per year. The oil that is produced must be transported to another place called the depots, where it is saved in big tanks and send later to the customers. These depots have specified and fixed capacities.

5.3.2 Vehicles Used

For the oil transportation, truck tankers are used. They come in various capacities, 35 m^3 and 40 m^3.Therefore only tankers of these capacities will be considered. Furthermore, heavier loads reduce number of trips.

5.4 DATA COLLECTION

As we mention in chapter three (3.4 data collection). Data for the mathematical experiment has been provided by an oil and gas company, State Oil Marketing Organization (SOMO). The company provided the data for two refineries and eight depots. Such as, oil production, the capacity for the refineries and the depots and, the distance between each refinery and depots.

5.4.1 Oil Production

A set of two refineries in the center of Iraq is selected. AL-Dura Refinery in the capital city for the state of Iraq sends oil production to some of depots (Resafa Depot, Meshahda Depot, Latefia Depot and Kut Depot). Beji Refinery in the north of Iraq sends oil production to (Khanqeen Depot, Ramadi Depot and Baquba Depot). Information concerning oil production for these refineries for the years 2006, 2007 was gathered. Phone calls and facility visits were made to get reasonably good estimates. This was done during the year 2010.

5.4.2 Refinery Oil Productions Capacity

All the seven depots gave their actual productions capacity approved by the oil marketing company (SOMO). Since their combined capacity is less than the total oil production for all the two selected refineries (AL-Dura Refinery and Beji Refinery), another depots was selected. The nearest depot was at AL-Anbaar (Falahat Depot). Now, the combined capacity of the eighth depots exceeded oil production for the two refineries.

5.4.3 Origin-Destination Distance Estimation

The origins were the refineries and the destinations were the depots. These distances were mostly actual miles by traversing to all the facilities in their respective locations (Table 5.1, Table 5.2).

Table 5.1: Origins and destination symbols

i / j	Latefia	Meshahda	Resafa	Kut	Khanqeen	Ramadi	Falahat	Baquba	AL-Dura	Beji
symbol	A	B	C	D	E	F	G	H	I	J

Table 5.2: Origin-destination distance matrix C_{ij} in Miles

i / j	A	B	C	D	E	F	G	H	I	J
A	-	63	41	62	104	92	63	67	20	157
B	63	-	23	125	64	88	57	55	39	118
C	41	23	-	103	95	79	48	39	20	135
D	62	125	103	-	144	166	139	115	82	217
E	104	64	95	144	-	146	117	34	101	214
F	92	88	79	166	146	-	27	180	85	119
G	63	57	48	139	117	27	-	207	57	90
H	67	55	39	115	34	156	131	-	70	248
I	20	39	20	82	101	85	57	70	-	157
J	157	118	135	217	214	119	90	248	157	-

5.5 THE ASSUMPTIONS

i. All oil produced at the refineries must be sent out to their respective destinations.

ii. Exactly the same # of trucks that go from refinery to depot return from depot to refinery.

iii. Each truck arrives at a depot as early as possible and leaves as early as possible also

iv. All vehicles are stationed at the refineries, unlimited in number and travel full-load.

5.6 OIL TRANSPORTATION MODEL

The transportation models that will be proposed in the coming sub-sections will be based on a basic model written by Winston (2004). There are a set of m supply points from which a good is shipped and there are a set of n demand points to which good is shipped. Each unit produced at supply point i and shipped to demand point j incurs a variable cost of C_{ij}. The number of units shipped from supply point i to demand point j equals X_{ij}. Thus, giving the following transportation model:

Minimize $\sum_{j=1}^{n}\sum_{i=1}^{m} C_{ij} X_{ij}$ (5.1)

Subject to $\sum_{j=1}^{n} X_{ij} \leq S_i (i = 1, 2, ..., m)$ (Supply constraints) (5.1.1)

$\sum_{i=1}^{m} X_{ij} \geq D_j (j = 1, 2, ..., n)$ (Demand constraints) (5.1.2)

$X_{ij} \geq 0 (i = 1, 2, ..., m; j = 1, 2, ..., n)$ (5.1.3)

The objective function minimizes the cost of transportation by summing up all products of cost per unit with the number of units transported for each origin-destination (i-j) pair. The supply constraints state a condition that for every supply point S_i, whatever is sent out to all destinations must not be more than the available capacity amount. Similarly for the demand constraints, the total supplies sent from all origins to a particular demand point must not be more than what is demanded by that destination D_j. The last set of constraints is the non-negativity condition. In the supply and demand constraints it is noticed as a basic rule that supply cannot be more than what is available, and satisfy demand up to what is actually demanded.

Specific to the models that are going to be constructed the following are defined.

The Index

i refineries

j destinations where oil production reach

The Decision Variable

X_{ij} Is the integer number of trips taken to transport an oil from origin i to destination j.

The Parameters

C_{ij} - Distance between refinery i and destination j

$D_j^{\,p}$ - Processing capacity of oil at destination j

$S_i^{\,p}$ - Total m^3 supply for oil at refinery i

$V^{\,p}$ - m^3 capacity of vehicle transporting oil

In a conventional transportation problem, a homogeneous product is to be transported from several sources to several destinations in such a way that the total transportation cost is a minimum. Suppose there are m supply nodes and n demand nodes. The *ith* supply node can provide S^{i} units of a certain product and the *jth* demand node has a demand for D_j unit as illustrated in figure 5.2.

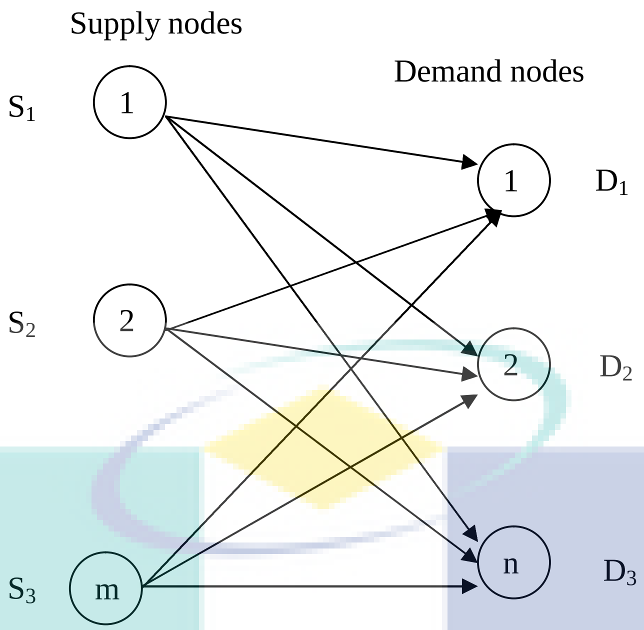


Figure 5.2: Origin-destination transportation network

In the oil industry there is a set of m refineries each supplying S_m m^3 of oil per day to another set of n depots, each with processing capacity of D_n m^3. Generally there is a set of m refineries each supplying $S_m^P m^3$ of oil and send to eight depots each with processing capacities of $D_n^P m^3$ of oil.

The transportation of products from the *ith* supply node to the *jth* demand node carries a cost of C_{ij} per unit of oil transported. The problem is to determine a feasible way of transporting all the available amounts without violating the demand or the capacity constraints of the receiving node that minimize total transportation cost.

The model is to assign right number of trucks to each route in order to minimize the cost of transportation and meet the volume requirements. Determine a feasible way of transporting the available products to their respective destinations at a total minimum haulage distance.

Transportation model can be simplified and much more easily comprehended by looking at the transportation problem of one oil product first. As depicted earlier there are the refineries as the supply origins and the depots as the destinations where oil will be delivered. The refineries have specific annual oil production and the depots have stipulated oil capacity. The problem is how to distribute the oil from the refineries to their nearest depots so that the total transportation is minimized. In essence the model is to find the best refinery-depot assignment so that total cost is minimized.

Let X_{ij} be the number of vehicle trips to transport oil productions from refinery i to depot j through a distance of C_{ij}. Thus models can be written as the following.

Minimize $Z = \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} X_{ij}$ (5.2)

Subject to $V\sum_{j=1}^{n} X_{ij} = S_i$, i = 1… m (supply constraints), (5.2.1)

$V\sum_{i=1}^{m} X_{ij} \le D_j$, j = 1… n (demand constraints), (5.2.2)

$X_{ij} \ge 0$, and integer $\forall i, j$

Where X_{ij} Number of vehicle trips from i to j,

C_{ij} Distance between i and j,

D_j Processing capacity of depot j,

S_i Supply at refinery i,

V Capacity of the tanker.

The objective function minimizes the total transportation distance in delivering oil from the refineries to the depots. The double summations (denoted by two sigmas, one after the other) indicate that the two variables are multiplied before their products are added up. The number of trips taken to deliver the oil between refinery i and depot j (this is the decision variable X_{ij}) is multiplied by the distance between them gives the total transportation distance for the specific i and j. The supply constraints consist of m equalities, each for a particular refinery. For each refinery, the number of trips that go out from that refinery to the depots multiplied by the size of the tanker must equal the total oil production of that refinery. Equal sign for these constraints also indicates that all the oil from the refineries must be sent out. On the other hand, the demand constraints which are altogether n in number, the amount of oil received by the specific refineries cannot be more than their saving capacities. The last constraints are the non-negative restriction on the decision variables and the number of trips must be integer numbers.

What the models are supposed to deliver is finding the optimal refinery - depot assignment. The approach in finding answer to the above is to run the program that is programming using, I-Log software as depicted in appendix D. I-Log software is powerful tool for rapid development and deployment of optimization models. It’s a better separation between data and model. Quadratic-programming (QP) support models with continuous and/or discrete decision variables.

5.7 RESULTS AND DISCUSSIONS

This section presents the output when the integer programming models were run on the computer. Data needed as the input for the programming runs are shown in tables. The output for the oil transportation problem is presented using the original locations of the refineries and depots. The results show the optimal refineries to depots assignments; that is which refinery will send its oil to which depot and by how much, so that total transportation distance and cost are minimized.

5.7.1 Input Parameters

In this section this study will show the important input parameters that we used with the model. Below, Table 5.3 give the truck type information for small and big trucks, Table 5.4 show the value of load time for each truck type, Table 5.5 give the earliest departure and latest arrive times for each depot, Table 5.6 show the shipment that will be carried back from a refinery to a depot by a truck, Table 5.7 give depicts the yearly cubic meter of the commodities for the two refineries, and Table 5.8 capacity for the depots.

Table 5.3: Truck type information

Truck Types	Capacity m^3	Speed miles/h	Cost $/miles
Small Truck	35	55	10
Big Truck	40	45	15

Table 5.4: Values for load time (minutes)

refinery	Small Truck	Big Truck
I	30	55
J	35	50

Table 5.5: Depot's information (minutes)

Depots	Earliest Departure Time	Latest Arrive Time
A	360	1080
B	400	1150
C	380	1200
D	340	900
E	420	800
F	370	1070
G	320	700
H	410	1100

Table 5.6: Shipments that will be carried back from a refinery to a depot

Origin	Destination	Total Volume (m^3)	Origin	Destination	Total Volume (m^3)
A	B	300	E	A	123
A	C	250	E	B	234
A	D	350	E	C	143
A	E	145	E	D	78
A	F	300	E	F	107
A	G	125	E	G	98
A	H	250	E	H	115
B	A	185	F	A	201
B	C	200	F	B	157
B	D	221	F	C	169
B	E	263	F	D	212
B	F	197	F	E	104
B	G	220	F	G	201
B	H	180	F	H	99
C	A	143	G	A	215
C	B	178	G	B	147
C	D	258	G	C	149
C	E	221	G	D	190
C	F	106	G	E	114
C	G	190	G	F	210
C	H	110	G	H	199
D	A	75	H	A	181
D	B	135	H	B	137
D	C	245	H	C	139
D	E	283	H	D	180
D	F	155	H	E	124
D	G	260	H	F	160
D	H	165	H	G	221

Table 5.7: Oil production for the refineries

Refinery Name	Oil Output (m^3 /year)	Oil Output (m^3 /week)
AL-DUARA	21590321	415198
BAEIJI	7216548	138779
Total Production	28806869	553978.25

Table 5.8: Capacity for the depots

Depot	Capacity (m^3)
Kut	85800
Latefia	501208
Resafa	385109
Meshahda	512534
Khanqeen	9910
Ramadi	123744
Falahat	43324
Baquba	46156
Total	**1707785**

5.7.2 I-Log Outputs

After running the program, we got three solutions with three objectives (see appendix C). Automatically I-Log software sign the optimal solution and it was be the third one with objective $388080. Table 5.9 shows the optimal values for earliest unloading time and latest in minutes for each route. Table 5.10 showed the possibly values of route and number of trucks for each rout and each type of trucks.

Table 5.9: Values for earliest unloading time and latest loading time

Routes	Values for Earliest Unloading Time (Minutes)		Values for latest Loading Time (Minutes)	
	Small Truck	Big Truck	Small Truck	Big Truck
< A, I, 20 >	412	442	1028	998
< A, J, 157 >	567	620	873	820
< B, I, 39 >	473	507	1077	1043
< B, J, 118 >	564	608	986	942
< C, I, 20 >	432	462	1148	1118
< C, J, 135 >	563	610	1017	970
< D, I, 82 >	460	505	780	735
< D, J, 217 >	612	680	628	560
< E, I, 101 >	561	610	659	610
< E, J, 214 >	689	756	531	464
< F, I, 95 >	504	552	936	888
< F, J, 80 >	493	527	947	913
< G, I, 87 >	445	491	575	529
< G, J, 75 >	437	470	583	550
< H, I, 70 >	517	559	993	951
< H, J, 248 >	716	791	794	719

Table 5.10: Values for possible truck on route and truck on route (solution 3)

Routes	Values for possible Truck on Route		Values for truck on Route	
	Small Truck	Big Truck	Small Truck	Big Truck
< A, I, 20 >	1	1	48	1
< A, J, 157 >	1	1	0	0
< B, I, 39 >	1	1	42	0
< B, J, 118 >	1	1	0	0
< C, I, 20 >	1	1	37	0
< C, J, 135 >	1	1	0	0
< D, I, 82 >	1	1	43	0
< D, J, 217 >	1	0	0	0
< E, I, 101 >	1	0	36	0
< E, J, 214 >	0	0	0	0
< F, I, 95 >	1	1	30	0
< F, J, 80 >	1	1	6	0
< G, I, 87 >	1	1	32	0
< G, J, 75 >	1	1	6	0
< H, I, 70 >	1	1	33	0
< H, J, 248 >	1	0	0	0

Through the outputs from I-Log program we got chart on the CPLEX statistics Fig. 5.3 the vertical axis of this chart is the value of the objective and the horizontal axis is time in seconds. The chart shows the variation of the best node and best integer values and highlights the integer values found during the search:

i. The green line shows the evolution of the Best Integer value, that is, the best value of the objective found that is also an integer value.
ii. The red line shows the evolution of the best value of the remaining open nodes (not necessarily integer) when moving from one node to another. This gives a bound on the final solution.

iii. The yellow point indicates a node where an integer value has been found. These points generally correspond to the stars (asterisks) in the CPLEX log.

The values in the discrete frame are dynamic and are updated every second; they change to indicate how the algorithm is progressing. The values in the General frame are static; they indicate the model characteristics.

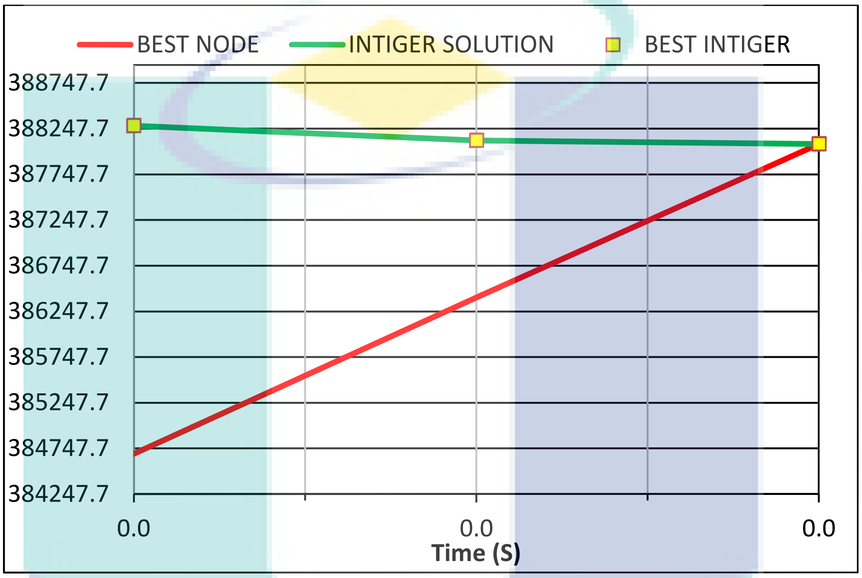


Figure 5.3: Chart on the CPLEX statistics page showed the objective value

5.7.3 Refineries - Depots Assignment

Given the supply of oil from Table 5.7 and the capacities of the depots from Table 5.8, the objective now is to find the optimal refinery to depots assignment so that total transportation distance is minimized, also the total cost is minimized.

The ILOG output of the integer programming for this model is shown in the columns labeled as ‘No. of trips X_{ij}’ in the Table 5.11. These are actually the values of the decision variables, X_{ij} which represents the number of trips taken by the trucks to transport all the available oil from each refinery as the origin to the depots as its destinations (one way) so that total transportation distance and the total cost are minimized. The above results show that to transport 415198 m^3/week of oil from the two refineries to the eight depots the minimum possible transportation distance is 19394

Miles, which is known in linear programming as the Z value. The minimum week truck trips needed to do the transportation of the massive commodity are 314 trips. This value comes by adding 302 trips, which is the total oil trips to the AL-Dura refinery, with 12 truck trips for the Beji refinery.

Table 5.11: Number of trips, distance and cubic meter from two refineries to depots in Baghdad and Beji

origin	AL-Dura				Beji			
	No. of trips X		Distance (Miles)	Volume (m^3)	No. of trips X		Distance (Miles)	Volume (m^3)
	Small Truck	Big Truck			Small Truck	Big Truck		
Latefia	48	1	20	1720	0	0	0	0
Meshahda	42	0	39	1470	0	0	0	0
Resafa	37	0	20	1295	0	0	0	0
Kut	43	0	82	1505	0	0	0	0
Khanqeen	36	0	101	1260	0	0	0	0
Ramadi	30	0	95	1050	6	0	80	210
Falahat	32	0	87	1120	6	0	75	210
Baquba	33	0	70	1155	0	0	0	0
Total	**301**	**1**	**514**	**10575**	**12**	**0**	**155**	**420**

Total capacity 1707785 m^3.

Total supply 415198 m^3/Week.

Total transportation distance is 19394 Miles.

Total transportation cost $388,080.

It is clearly seen in the results shown in the table above that the refineries located above in the center and north send their oil to the depots at Baghdad, Al-anbaar, Kut and Diala. Total oil transported from AL-Dura refinery is 10575M^3. The other refinery in Beji got deliveries totaling 420 m^3.

A total of 10575m^3 of oil is sent to eight depots although their combined capacity is 1707785 m^3, nearly 1698000 m^3 under-capacities. Simple explanation here is refinery at Beji is nearer to Ramadi and Falahat depots than to AL-Dura refinery, so instead of sending oil from AL-Dura refinery just to satisfy capacity requirements, it is better sent from Beji since the objective is to minimize the transportation cost.

In terms of total trips that go to Baghdad depots, there are altogether 302 trips and to Beji facility are 12 trips. At 24 working hours a week, a daily average of 8 trucks will queue at each of the depots in Al-Dura. A look at the first refinery depot (Resafa) shows that it takes 37 trips to haul 1295 m^3 of oil in a span of a week. three trucks are expected to leave the mill per week, not a busy situation for this small Resafa facility. As a comparison, the Latefia depot with 48 loaded tanker trucks leaving this premise for its destination in a week could be considered busier since on a daily basis it is seen more than 5 trucks going out.

Looking at distance, to transport 10575M^3 of oil to the Baghdad depots distance recorded was 514 Miles, whereas for 420 m^3 distance to Beji was only 155 Miles. It is noticed here that although amount of oil to AL-Dura is 25 times more than that to Beji but distance is only 3.3 times more, the reason being cluster of depots around Baghdad are closer to their refinery (AL-Dura) than those depots around Beji, which are further spread out from their assigned depots. Observing transportation distance to Baghdad depots, Khanqeen has the highest at 101 Miles.

It is noticed that total capacity of the eight depots in the two locations exceeds total oil supplies from the two refineries by nearly 1292587 m^3. Thus, it is fair to expect in the result that none of the depots work at its full capacity, although it was informed by the managements that their facilities are working at full capacity. This leads to the conclusion that when the governing authorities assign capacities to these destinations, distance traversed from their origins is never of prime consideration.

One way to save the inefficient traveling is by increasing the oil production in the two refineries that have been assigned to the Baghdad and Beji by the proposed model, if they have not reached maximum production capacity. If the depots all working at full capacity it makes sense to approve a future refinery, at the proximity of the Baghdad area.

5.8 SUMMARY

At optimality it is found the best refinery -to- depots assignments. This study found the minimum possible transportation cost. Two refineries that form a cluster, from the center at Baghdad, Iraq and Beji, Iraq send their oil to depots. The AL-Dura refinery with total production 415198 m^3 /week and the total capacity for the assigned depots was 1707785 m^3. The other refinery at Beji 138779 m^3/week and the total capacity of the assigned two depots was 167068 m^3. The total transportation distance to implement the above assignment is 19394 Miles for one way trip (38788 Miles for two ways). The total transportation cost is $388080 /week, this value will divide to find the average total cost per truck per trip, and then we use it with the simulation model as input parameter (see Table 3.1).

CHAPTER 6

DEVELOPING A COMPUTER – BASED DECISION SUPPORT SYSTEM

6.1 INTRODUCTION

A decision support system (DSS) is a computer-based system developed to assist a decision maker to make a credible decision in various fields such as engineering, business, the medicine, and military. They are particularly valuable in conditions in which the total of attainable information is prohibitive for the guess of an unaided decision maker and in which accuracy and optimality are of importance (Marek and Roger, 2002). In chapters 3, 4 and 5 two models were developed using DES and LP methods and did all the experimentation to represent the real system.

In this chapter, an integrated computer - based decision support system was developed to investigate and improve the petroleum transportation system of a representative oil supply and transport problem. The system is based on the integration of discrete event simulation (DES), analysis of variance (ANOVA) and mathematical linear programming (LP) of the oil transportation system. The system can aid the decision maker’s cognitive deficiencies by integrating various sources of information, providing intelligent access to relevant knowledge, and assisting the process of structuring decisions. Suitable application of decision-making tools increases efficiency, productivity and effectiveness. The system is allowing a decision maker to do optimal choices for system operational processes and their parameters.

First we used the mathematical LP to design an input of all needed parameters. The LP model made by I-Log software and the controller is coded by VBA, this code used in PTMS for calling and embedding LP model.

The simulation model used in the study is developed using a simulation tool, ARENA and the controller is coded using visual basic applications (VBA) that is embedded in ARENA. Finally create an interface between the simulation model and the controller, and then run optimization process. Figure 6.1 shows the connections between ARENA tool and the VBA language.

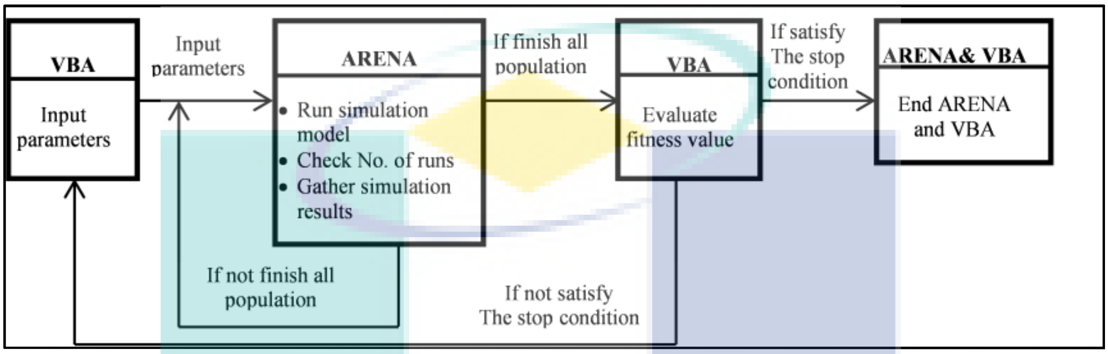


Figure 6.1: The Model Process between ARENA and VBA

6.2 DECISION SUPPORT SYSTEM

Decision support systems (DSSs) are interactive, computer-based systems that aid decision makers in judgment and choice the right activities. They provide data storage and retrieval but enhance the traditional information access and retrieval functions with support for model building and model-based reasoning. They support framing, modeling, and problem solving. DSSs are usually used for strategic and tactical decisions faced by top-level management-decisions with a reasonably low frequency and high potential consequences-in which the time taken for thinking through and modeling the problem pays off generously in the long run.

There are three fundamental components of DSSs (Andrew, 1991).

i. Database management system (DBMS). A DBMS serves as a data bank for the DSS. It stores large quantities of data that are relevant to the class of problems for which the DSS has been designed and provides logical data structures with which the users interact.

ii. Model base management system (MBMS). Role of MBMS same of DBMS. Its main function is to provide independence from specific models used in DSS with applications that use them. The purpose of MBMS is to convert data from DBMS to information useful to decision making.

iii. Dialog generation and management system (DGMS). The main product of an interaction with a DSS is insight. DSSs need to be equipped with intuitive and easy-to-use interfaces. These interfaces are aid in building a model and also in interaction with the model such as gaining insight and recommendations.

While a variety of DSSs exists, the previous three components can be found in many DSS architectures and play an important role in their structure. Fundamental interaction between them is illustrated in Figure. 6.2. Basically, the user engages with the DSS through the DGMS. This communicates with the DBMS and MBMS, which screen the user and the user interface from the physical details of the model base and database implementation.

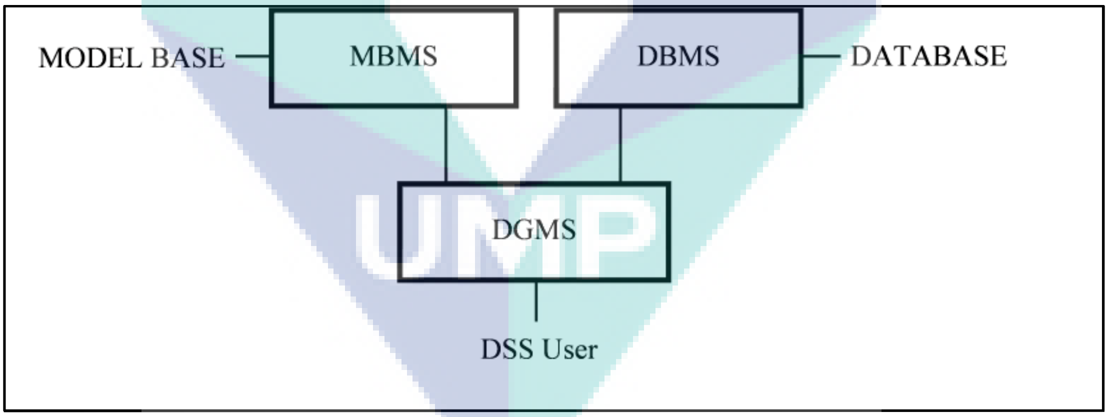


Figure 6.2: The architecture of DSSs (Andrew, 1991)

6.3 USER INTERFACES TO DSSs

While the reliability and quality of modeling tools and the internal architectures of DSSs are important, the most crucial aspect of DSSs is, by far, their user interface. Systems with user interfaces that are cumbersome or unclear or that require unusual skills are rarely useful and accepted in practice. A good user interface must support model developing and model analysis, reasoning about design problems, in addition to numerical calculations, and both selection optimization of the decision variables. More discussion on this is shown in following sections.

6.3.1 Support for Model Developing and Model Analysis

Graphical interface is the guide for either model building or model choice and for examining the results. Even if the model is based on theoretically sound perceptive scheme, its commendations will be as respectable as the model they are based on. Furthermore, if the model is a truly good approach of actuality and its suggestions are correct, they will not be followed if they are not understood (Marek and Javier 2000, Marek at el. 2000). Some indicators to work on support for building decision-support model as illustrated in patent documents (Gary et al., 2010 and Song at el., 2010).

6.3.2 Support for Choice and Optimization of the Decision Parameters

Lots of DSSs have an Inelastic structure in the sense that the parameters will be managed are determined at the system building steps. This is not very proper for planning of the strategic kind when the object of the decision-making process is classifying both methods and objectives of accomplishing them. Support for both choice and optimization of the decision parameters should be an inherent part of DSSs.

6.3.3 Graphical User Interface

Understanding a model can be much better at the graphic user interface level by a chart representing the relations among its elements. As models may become very large, it is suitable to building them into sub-models, groups of variables that form a sub-system of the modeled system. Such sub-models can be once more shown graphically with connections between them, increasing simplicity and clarity of interface.

6.4 INTEGRATED DECISION SUPPORT SYSTEM

From the understanding about and the analysis into the system, linear programming (LP) and simulation models are built so as to represent faithfully the activities of the current system. Then manager or decision makers can examine the performance of the developing model in many different situations and obtain insight into the characteristics of the system. Therefore, before actually implementing any design or control decisions, the decision makers can compute or forecast the conclusion of the decisions on the developed model performance. The decision makers can also calculate many different control policies and select proper plausible policies to implement on the current developed system as depicted in Figure 6.3. Meanwhile, an optimum control problem can be formulated and solved to discover the optimal or near-optimal control policy more systematically and efficiently. Decision makers can use these solutions as a reference and improve the performance of the petroleum transportation management system (PTMS) by creation more informed conclusions.

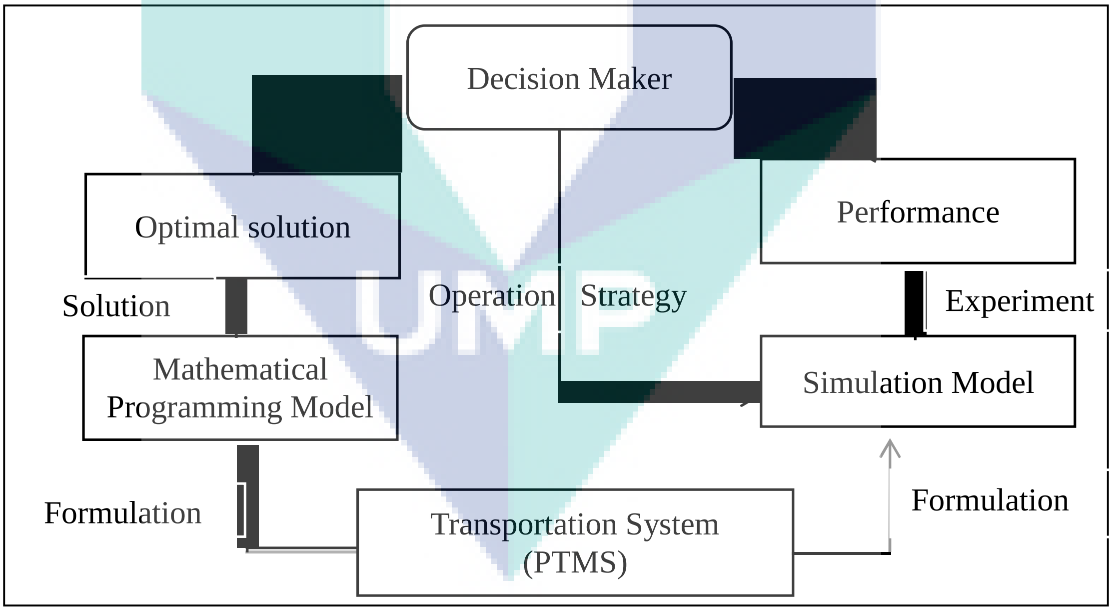


Figure 6.3: An Integrated Decision Support System

The current model in practice involves enormous complexity and uncertainty, and it is clearly also changing over time. It is critical to have validating and updating the developing simulation model and the LP as the real system. As the decision makers interact with and learn from the developed model, more insightful understanding and accurate information can be achieved to improve modeling of the current system, which in return improves the system performance by supporting decision makers choose the right decisions.

To provide the decision maker with a decision support system based simulation and LP and developed an independent framework that integrates the simulation & LP models and controller to help the decision maker to manipulate the developed model by the controller. Simulation and LP architecture also contains of an interface so that users can identify the original conditions and parameters and find results through the developed model.

As shown in Figure 6.4, the model (LP and simulation) that represents the behavior of the real supply and transportation system is constructed in I-Log and Arena, together combined in VBA modules.

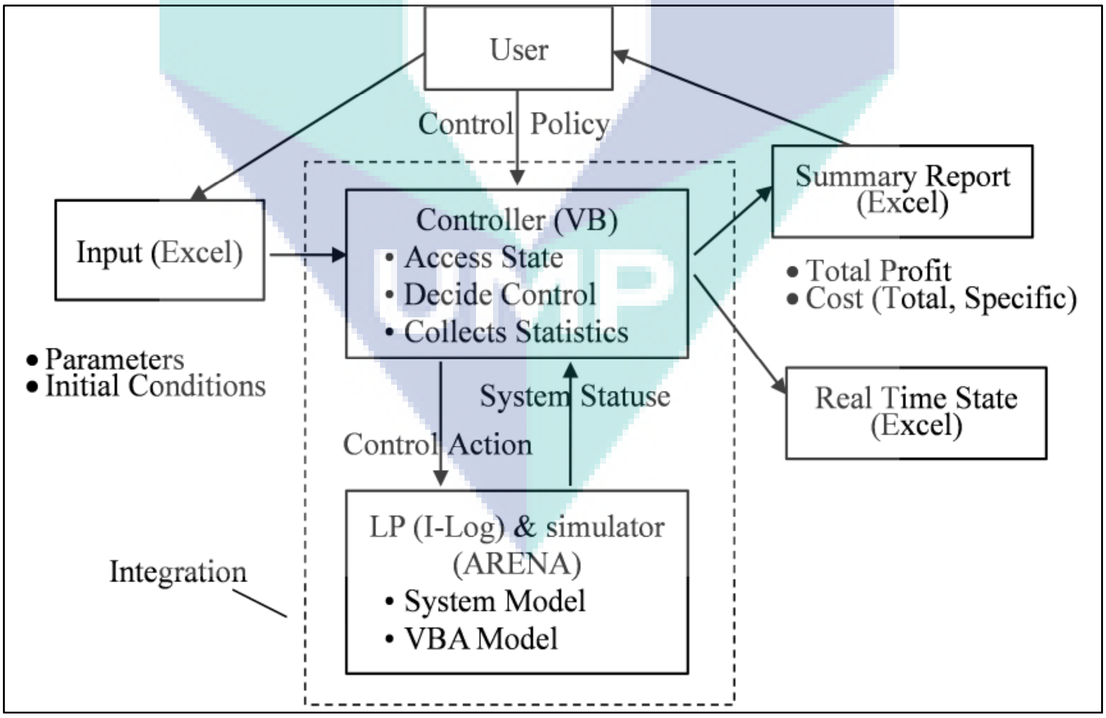


Figure 6.4: The Framework for Simulation

By VBA modules, the controller, which is instigated and coding in a Visual Basic (VB), can access the state parameters in the developed simulation system same thing with LP system through the progression of simulation run and can deal with the simulation by changing factors values and entity attributes, etc. Additional the VB based controller is that it can computerize other applications such as Microsoft® Excel. Therefore, a user input/output (I/O) interface was created automatically through Excel inside the ARENA software. For example, when the simulation model is running at the beginning, decision makers can specify the input parameters to the simulation model such as decision factors value and initial conditions via Excel. Also when the simulation model is run, the real time state of the model can be showed through Excel and updated as the simulation proceeds. In the end of every replication, information of the cost and system statistics collected and computed by the controller can be saved as Excel file. Therefore, a statistical analysis can be conducted after complete all replications of the simulation system.

6.5 CONTROLLER DESIGN

In order to develop the PTMS that is modified and controlled by a controller, the simulation and mathematical programming models with the controller is integrated. The controller should be able to access the state information and deal with variables or perform actions in anytime during the simulation model running as illustrated in figure 6.5. The integrated system is built through ActiveX control automation, which lets applications to control each other and themselves via a programming user interface.

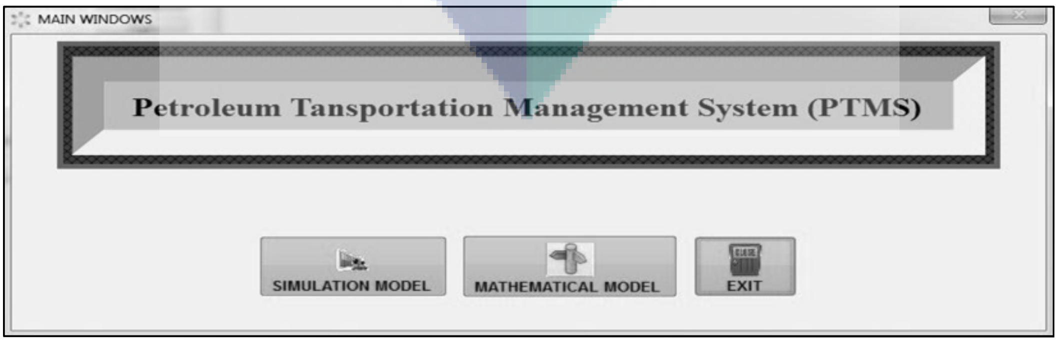


Figure 6.5: The main window controller

When an event is started in I-Log or ARENA, the responding VBA code in the Visual Basic system will be executed.

Many different procedures that start the VBA project and corresponding actions performed through VBA project, as illustrated in table 6.1.

Table 6.1: Firing events in the VBA object

Firing Event	Occurrence	Actions
Main Window	Start the program with main window	Choose and run simulation and mathematical programming models
Mathematical Model	Run the model using I-Log	• Design and run the mathematical model through I-Log software • Show the optimal solution
Simulation Model	Run the model using ARENA	• Input New Parameters • Run the Model • Do the Experimentation • Scenario Results

6.5.1 Design of Mathematical LP Model

First, call LP model using I-Log software through object linking and embedding (OLE) by press on mathematical model command as depicted in Figures 6.5 and 6.6. All parameters should complete to start run the model using the support file to save the parameters, the extension for this file is *.dat. Input parameters mean the distance between the refinery and each depots, the cost for usage truck, oil production and each depot capacity as depicted in Figure 6.7.

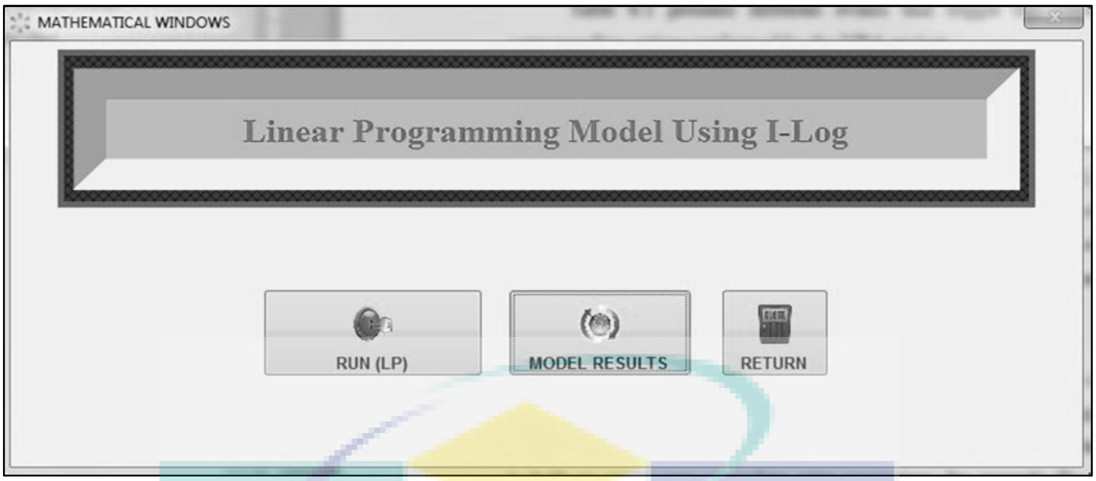


Figure 6.6: Mathematical model (LP) – main window

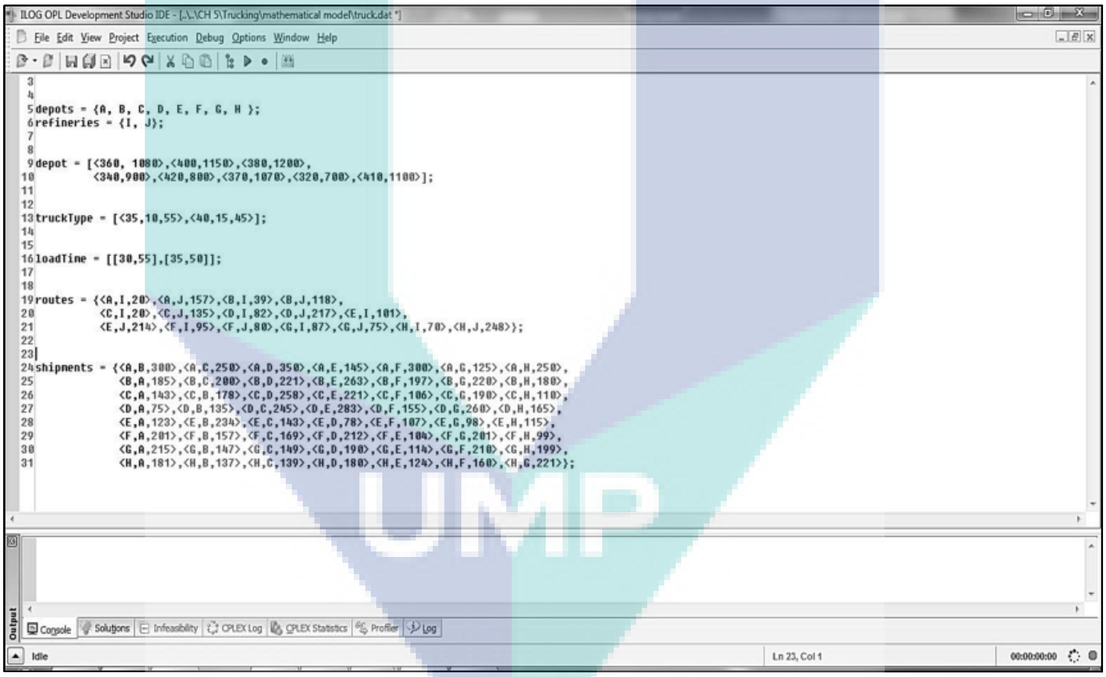
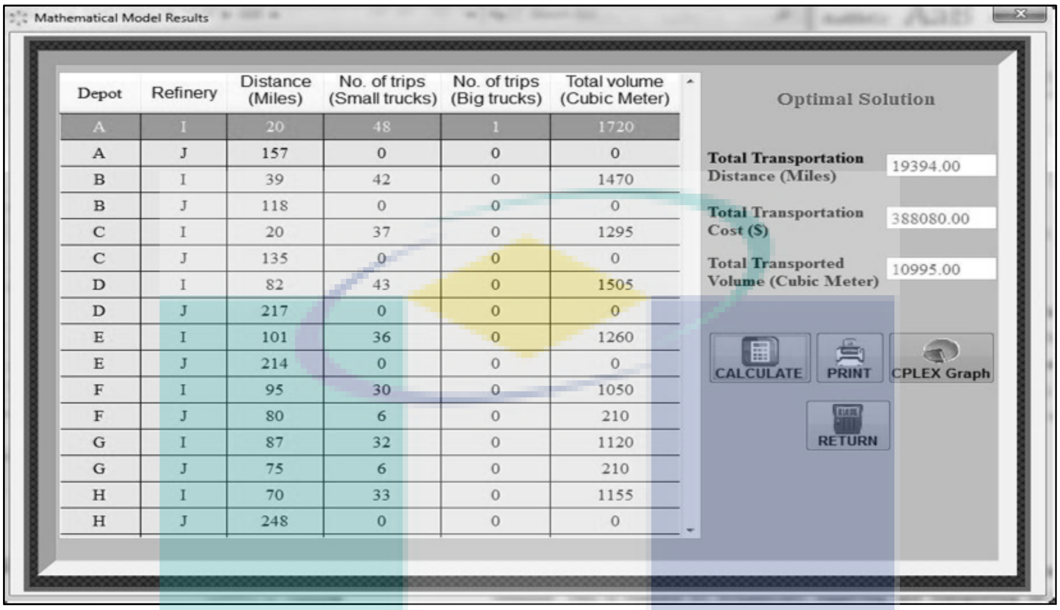


Figure 6.7: I-Log software – input parameters and run the model

6.5.2 Show the Mathematical Model of LP Results

After designing the LP model and inputs the parameters, the result will be ready to run by clicking on the model results command. There are two types of results; data browse is illustrated in Figure 6.8 to show the No. of trips and the total transportation distance and the total transportation cost, the second type of results is graphical window as depicted in Figure 6.9 named CPLEX graph to show the alternative solutions and the best node is optimal objective value.



Depot	Refinery	Distance (Miles)	No. of trips (Small trucks)	No. of trips (Big trucks)	Total volume (Cubic Meter)
A	I	20	48	1	1720
A	J	157	0	0	0
B	I	39	42	0	1470
B	J	118	0	0	0
C	I	20	37	0	1295
C	J	135	0	0	0
D	I	82	43	0	1505
D	J	217	0	0	0
E	I	101	36	0	1260
E	J	214	0	0	0
F	I	95	30	0	1050
F	J	80	6	0	210
G	I	87	32	0	1120
G	J	75	6	0	210
H	I	70	33	0	1155
H	J	248	0	0	0

Figure 6.8: The optimal solution for LP model – data brows results

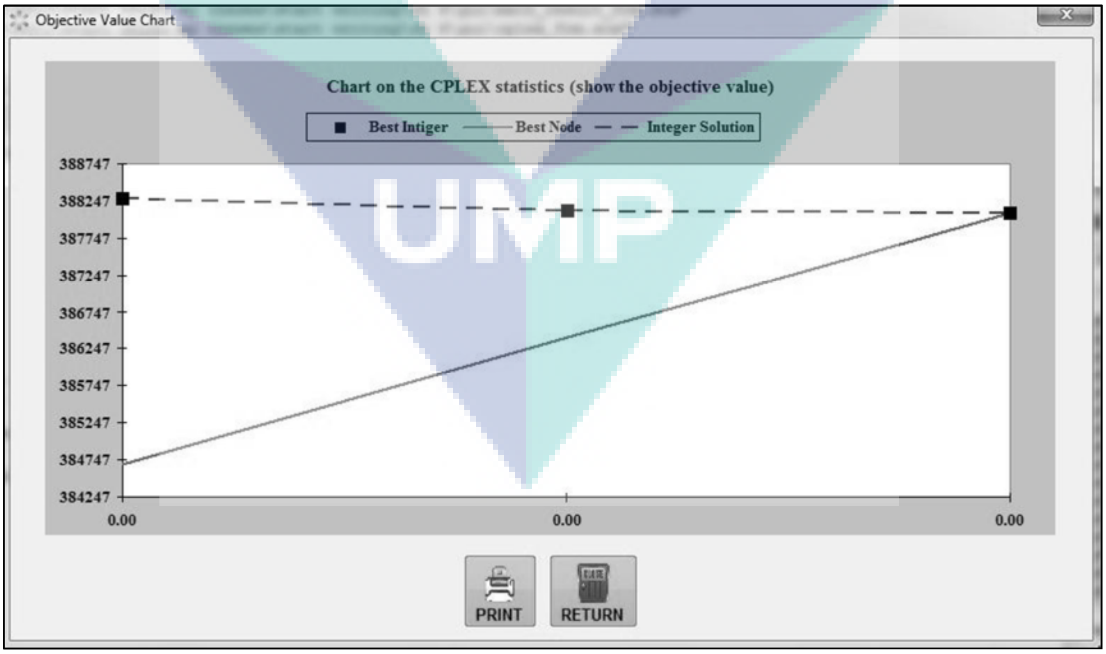


Figure 6.9: The optimal solution for LP model – CPLEX graph

6.5.3 Design of the Refinery Terminal Parameters (Simulation Model)

The controller and related variables, such as the *Truck Fill Time* that process the Time required to fill oil into a truck, and calculate total supply and transport cost information, are all instigated in VBA system.

Factors level and input parameters decisions have to be selected on composition and sizing of the oil refinery terminal. This is understood by dynamically supplying and transporting oil by trucks from refinery to depots at different locations. A New Parameters module (command) is built to create new or update exist parameters: for example *Truck_TBA* at the beginning of each period (55, 75, 95 and 115 minutes) when needed according to the input parameters policy as depicted in Figure 6.10.

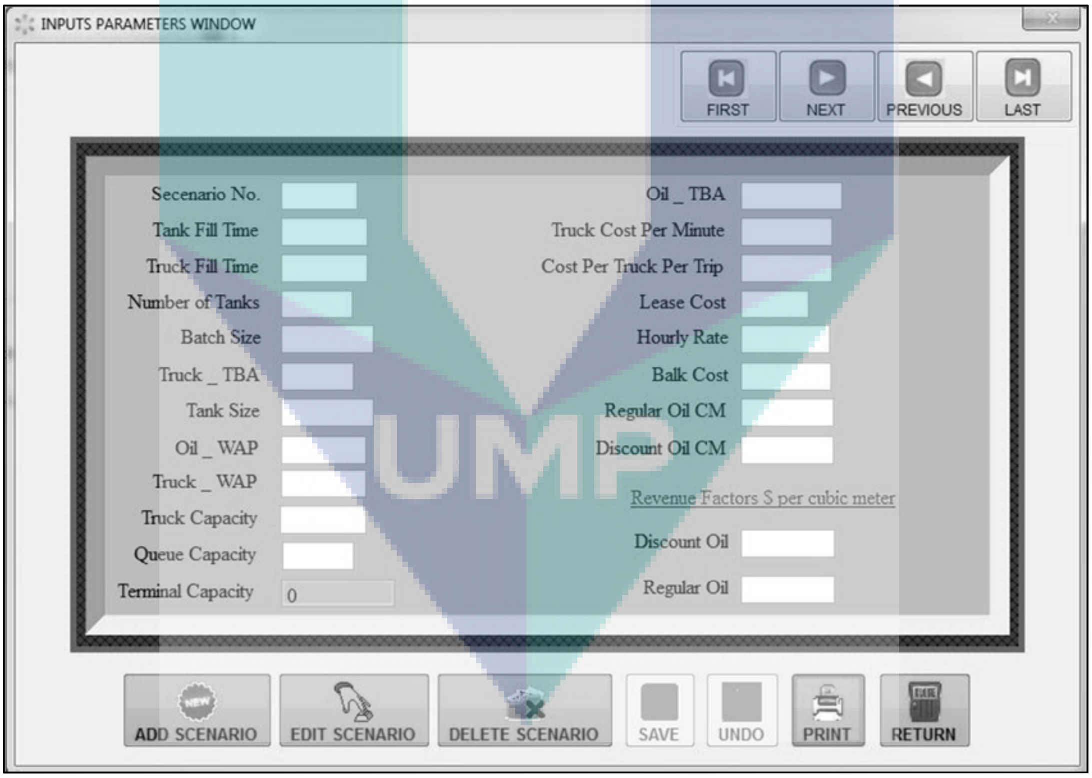


Figure 6.10: Simulation model- Input parameters

The next VBA module will call the ARENA software through object linking and embedding (OLE) object to run simulation project and the output will be Excel sheet is illustrated in Figure 6.11.

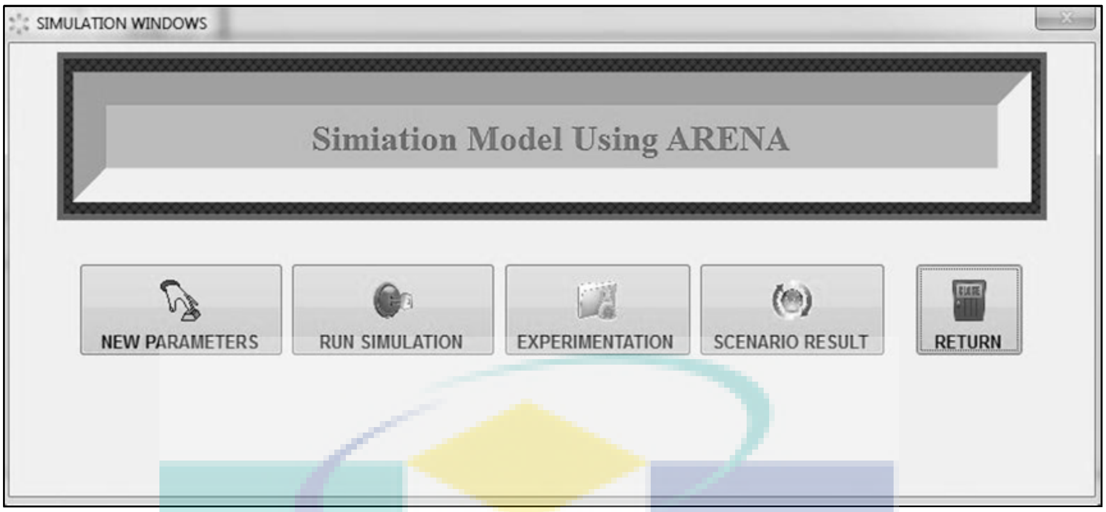


Figure 6.11: Simulation model – main window

After developing simulation system and the controller, and specifying the input parameters and control policy, we can run the simulation model and view the results. In this study we are interested three types of results shown in following sections:

i. Graphical animation

Animation provides a mean of observing the objects flow through the system. As shown in Figure 6.12, which is a photograph of the animation when the simulation model is running, the modeler is able to see trucks arriving at the terminal supplying points. The animation can also visualize the movement of other objects such as oil that is either stored in the tanks or moving through the pipeline, and the orders for oil waiting in a queue which shows a demand shortage. Besides entity flows, ARENA is also capable of visualizing some information of the developed system, for example, the simulation date/time, the system variables such as oil inventory level and number of trucks balk from the system.

ii. Real-time state-space report

Animation gives limited the ability to report the state space information dynamically. In order to have a more detailed and flexible report on the real-time system state, the integrated system utilizes ActiveX control automation to create an Excel file and display the real-time state information via the spreadsheet. At the beginning of the simulation run, a new Excel spreadsheet is created. The VBA code representing the controller is activated by a control entity at the beginning of each time. It accesses the current state of the system, updates the state parameters and writes them into the Excel spreadsheet. So, users can view the real time state information of the system which is updated dynamically via the Excel spreadsheet.

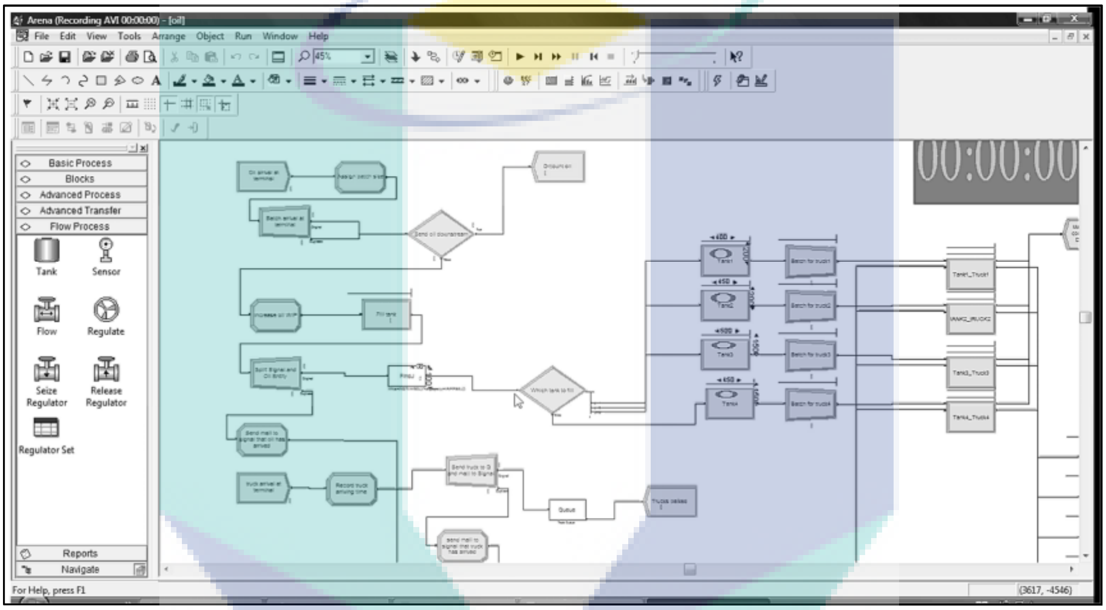


Figure 6.12: The animation when the simulation is running

iii. Summary report

Through the simulation model run, VBA code in the controller computes the supply and transport of cost information and collects system statistics such as utilization of the different types of *Tanks Capacity*, *Truck_TBA* and *Tanks Number*. This information represents the system performance measure of interest, which is stored in another Excel spreadsheet at the end of each replication. Excel spreadsheet in Figure 6.13, provides an example of the summary report, which stores the profit information including *Number of Tanks*, *Tank Capacity* and *Truck_TBA*, and system statistics charts.

Number of Tanks	Tank Size	Truck TBA	Avg. Total Profit/Wk
1	48	55	242.48
1	48	75	381.46
1	48	95	447.81
1	48	115	451.99
1	56	55	286.91
1	56	75	417.93
1	56	95	449.08
1	56	115	440.37
1	64	55	288.99
1	64	75	414.61
1	64	95	427.29
1	64	115	415.52
1	72	55	270.16
1	72	75	397.3
1	72	95	401.07
1	72	115	388.04
2	48	55	559.27
2	48	75	697.79
2	48	95	646.79
2	48	115	565.28
2	56	55	575.96
2	56	75	706.51
2	56	95	620.32
2	56	115	525.9
2	64	55	551.23
2	64	75	676.39
2	64	95	571.72
2	64	115	474.25
2	72	55	505.89
2	72	75	632.57
2	72	95	518.99
2	72	115	420.26
3	48	55	500.3
3	48	75	740.11
3	48	95	641.25

Figure 6.13: An example of the summary report

6.5.4 Simulation Model Experimentation

This module will help a decision maker to do all the graphics statistical analysis directly from the system PTMS or call statistical package for the social science (SPSS) through OLE.

There are two types of experimentation, single factor analysis and two factor analysis as depicted in Figures 6.14 and 6.15.These illustrations indicate how average total profit per week changes as these factor-levels increase or decrease. Also, insight can be gained on how the two-factor interactions significantly impact average profit per week.

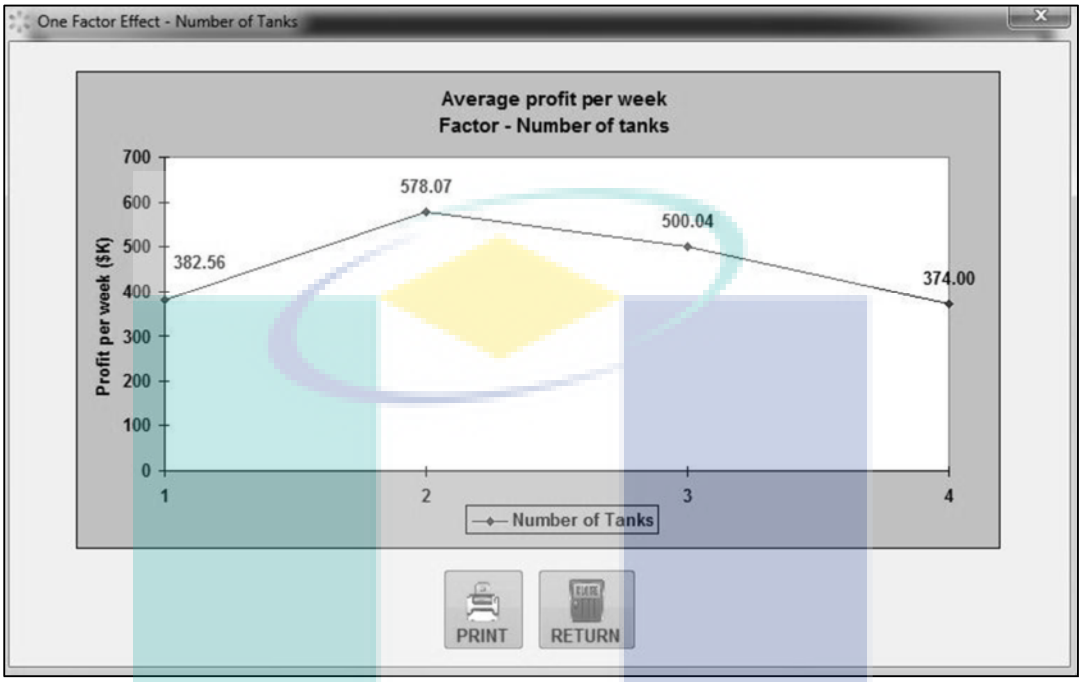


Figure 6.14: Simulation model – Experimentation-One factor analysis window

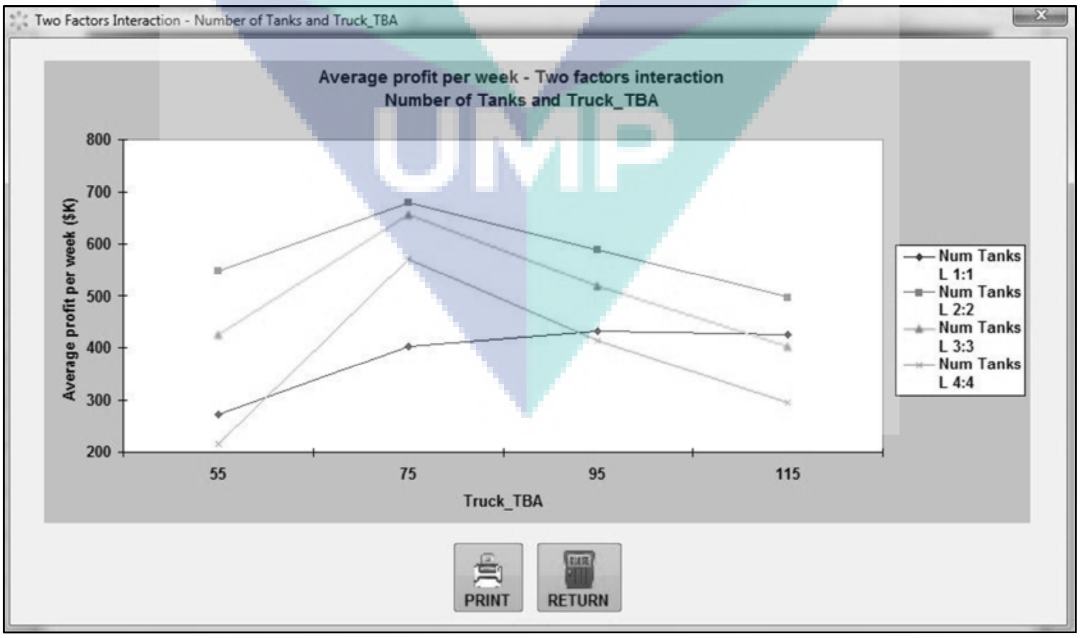


Figure 6.15: Simulation model – Experimentation-Two factors analysis window

6.5.5 Run Scenarios

To start the estimation process, an initial run of 180 weeks with 20 weeks of warm-up period with ten replications were conducted for many different scenarios and the total profit week ($K) for each run was compiled in scenarios result window as depicted in Figure 6.16. Also each scenario can print and copy to spread excel sheet.

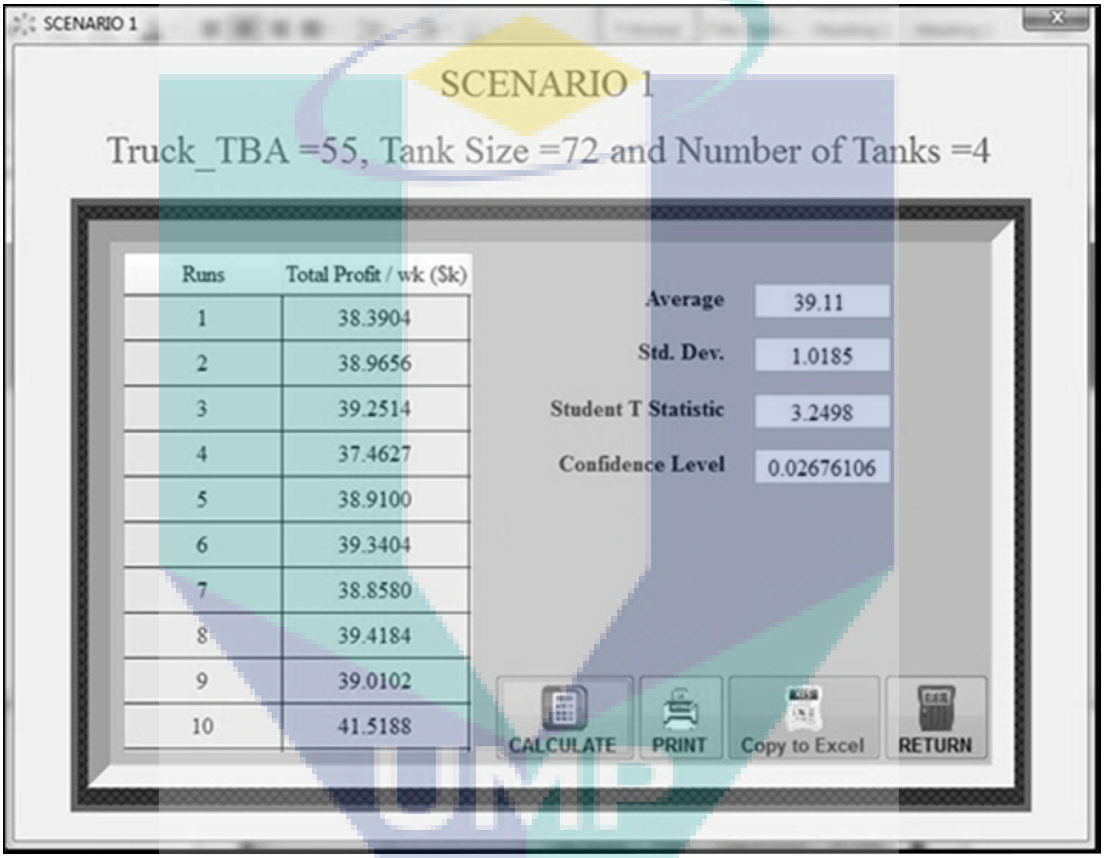


Figure 6.16: Simulation model – Experimentation-Run scenarios window

6.6 STATISTICAL ANALYSIS

After setting up experiments and running many of replications, the user collect an important amount of information about the system behavior and performance measure in a specific condition. As discussed in earlier sections, after finished the mathematical model and simulation models, a summary reports will showing the performance measure or system statistics, e.g., total transportation cost and total profit

$/week for each replication. The scenarios represent by the replications that could physically happen in reality, and also using independent random numbers. Therefore, the performance measure and system statistics of all replications practically represent the possible performance and behavior of the current system given a certain condition. From the performance measures in the summary reports for each model, automatically will get the graphic results and statistics data, or the decision maker can use SPSS by the system to analyze and interpret the simulation results as illustrated in Figure 6.17, which is one of the objectives of the simulation study.

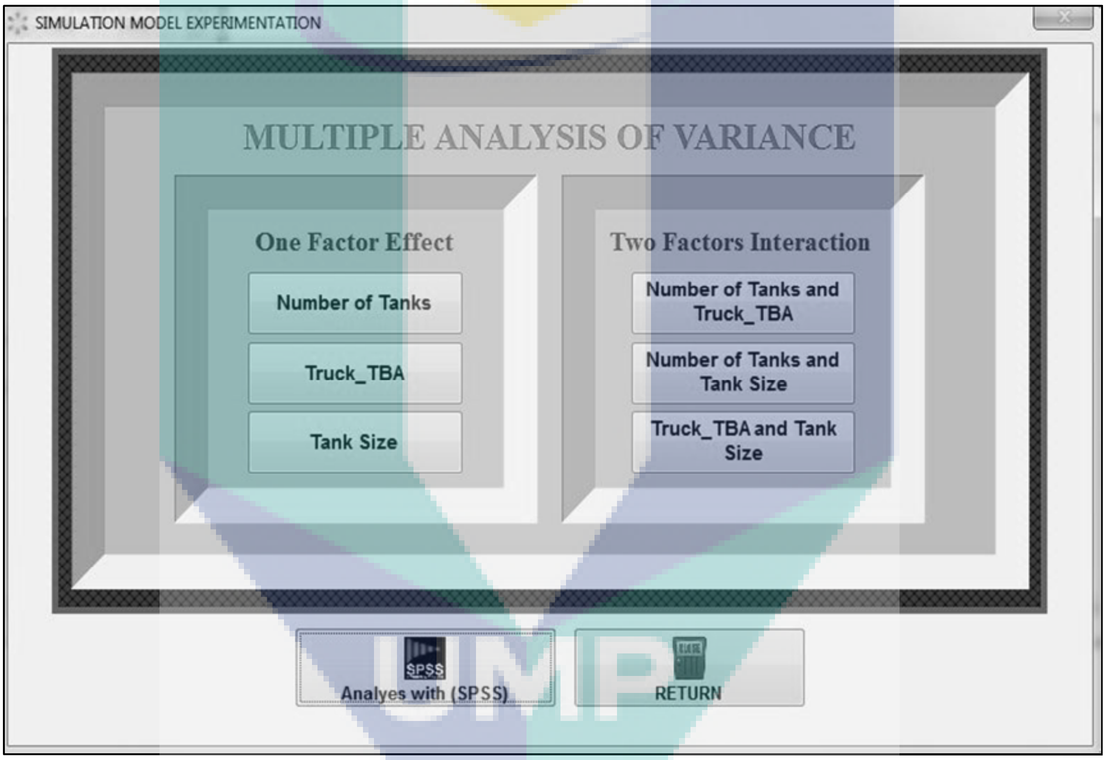


Figure 6.17: ANOVA single and two factors statistics

Consider a situation where the decision makers are deliberating on how to build or develop oil refinery terminal to meet the demand and maximize the total profit. One of the questions that they have to answer is "How many tanks and what is the tank capacity shall we hire?" The answer to this question includes a tradeoff between the costs of renting and maintaining the tanks, and the potential costs of penalties for not satisfying the demands. It is impossible to find quantitative answers to such questions by simply using intuition, as the nature of the system is too complex to forecast its behavior through intuition. Simulation model provides a valuable tool to support decision makers choose the alternative decisions, e.g. “what if ...” For example, the decision makers could consider four choices for sizing the tank, 48000 m^3, 56000 m^3, 64000 m^3, or 72000 m^3. The system contained the different decisions into the simulation model and run four different scenarios for a length of 180 weeks, each with the same initial conditions, control policy and replication number. After running a specified number of replications, the distributions of the performance measures can be plotted and other statistical measures, such as the estimate of expected value and confidence intervals can be estimated from the samples as depicted in figures 6.14, 6.15 and 6.16.

6.7 SUMMARY

This chapter is concerned with developing a decision support system (DSS) to support decision makers choose the optimal values of each factor and parameter to maximize the total profit for oil supplying and transportation system. The integration of DES and LP of the combined supplying and transportation system provides the foundation for the decision support system. The integrated models are formulated in a consistent and interactive manner so that the insight and results obtained from either one can be utilized to validate and improve the other.

A unifying framework was developed that integrates the simulation and LP models with a built-in controller through ActiveX control automation. Simulation model is built to represent the real oil supplying system. LP is developed to find the optimal minimum distance and minimum total cost of oil transportation from the refinery to the depots. Also a graphical interface was developed for users to input system specifications and view reports on the real time information as well as the current system performance measures. The decision makers can examine the behavior of the system and calculate the performance of many different strategies by simulation models and LP of the controlled system. The design decisions are made on a weekly basis to determine the total profit and also to find the minimum total cost for oil transportation from the refineries to the depots.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1. INTRODUCTION

In chapter 6, an integrated computer - based decision support system was developed to investigate and improve the petroleum transportation system of a representative supply and transport oil refinery problem. The model is based on the integration of discrete event simulation (DES), analysis of variance (ANOVA) and mathematical linear programming (LP) of the oil transportation system.

In this thesis, two models simulation and LP have been developed with the aim of maximizing the total profit and minimizing the transportation cost of an oil refinery terminal. Also a decision support system with statistical analysis have been developed to support a decision maker, who is planning to build a new facility or expand an existing oil refinery terminal, should be able to choose the optimal value for all important factors and parameters.

7.2. CONCLUSIONS AND RECOMMENDATIONS

The first objective is to develop a generic simulation model to present a model by which a decision maker should be able to choose the optimal number of tanks, tank size and truck arrival rate that will maximize average total profit per week for the oil refinery operations. Given an oil flow rate and a total cost and contribution margin structure, the profitability model is able to predict with a 99% confidence level, a group of factor-level mix, which will yield the highest average total profit per week. Out of a possible 64 combinations, 6 factor-level mixes have been identified to be not significantly different from each other and yield the highest average total profits per week. So, how does a manager choose amongst the six combinations? The answer lies in understanding the business metric that will drive the decision making process. For example, if the business manager expects future opportunities for growth, then the manager should choose the solution which allows for additional oil tanks station capacity.

The growth opportunity could arise due to an increase in regular oil demand or price, an increase in the oil arrival rate into the oil refinery terminal, or a decrease in the discount oil price that makes the sale of regular oil more desirable. The solution the manager would then choose is 3 tanks each with a capacity of 56,000 m^3 (see table 4.13). Another business metric the manager may have to satisfy is the regular oil demand rate. There may be a percentage of oil that has to be shipped through the regular stream to satisfy customer need. In this instance, the manager could choose the solution that yields the highest percentage of oil shipped through the regular channel. Once again, the solution the manager would then choose is 3 tanks each with a capacity of 56,000 m^3. What if the manager anticipates that in the future the transportation cost is going to increase? In this case, once again, the manager would choose 3 tanks each with a capacity of 56,000 m^3, this yields the lowest average truck cost as a percentage of total cost.

The second objective is to develop a generic transportation linear programming (LP). A model was built to find the optimal assignment refinery-to-depots, so that oil transportation achieved the minimum distance and cost of the objective function. Although the model was very basic in terms of having only two sets of supply and demand constraints, but flexible enough to have many ‘what if questions’ answered by just a simple change in the equality/inequality signs and right hand side parameters. The output of the I-Log program was the assignment of the refineries to the depots. The assignment was a very natural one. Conveniently the solution exhibited two clusters of refineries assigned to two locations where depots are located. The refineries that located in north or south send their oil to the nearest depots. The optimization technique is powerful in this partition of the ‘north’ and ‘south’ clusters. Without optimization, there is no way one can manually draw the line between the two sets of refineries and depots.

This is especially true when at optimality both of any depots, still do not operate at full capacity. When refineries are permanent at their present locations, the research is interested to find out true optimal locations for depots so that the distance burden of moving this massive amount of product can be minimized.

The third objective is to present a DSS, an overview of simulation and LP modeling parameters which could be used as a management decision-support tool assisting in evaluating and improving the comprehensive oil refinery operations. The results of the models (simulation and LP) were also described the statistical data analysis and the analysis of operational performance of oil refinery terminal. The data analysis includes the single and multi-factors graphic analysis.

The fourth objective is develop petroleum transportation management system (PTMS) based on the simulation & LP models and visual basic (VB) to investigate the behavior and improve the performance of the developed system. Management can use this system to predict the combination of the decision factors (*truck_TBA*, *number of tanks* and *tank size*) to yield the highest average profit per week. The input variables include the oil arrival rate in the oil tanks station, the cost and contribution margin structure, the tank fill rate, truck fill rate and the oil batch size coming into the oil refinery terminal. The system presents a procedure by which the decision maker can manipulate the input variables to retrieve the most profitable factor-level combination.

The simulation and LP models constructed in this thesis have the potential of being extremely useful in assessing and analyzing different strategies in the planning and management of the oil refinery terminal. The simulation and LP models are also useful for forecasting the likely effects on system performance of any physical and policy changes.

7.3. SUGGESTIONS FOR FURTHER RESEARCH

Due to complications in modeling, the quality test, which requires holding an incoming batch of oil for 24 hours, was ignored. Further study could be done to incorporate the quality test procedure to understand the impact on the results. Another limitation of this study was that only one transport vehicle type (trucks) was used. It would be interesting to understand the impact on results if different transport vehicles (for example, trains) could be used with fixed and random arrival schedules. Finally, throughout the study, the oil fill rate into the terminal and truck fill rate was assumed to be constant. Further studies could be conducted to see if varying the fill rate would have any impact on the results.

With demand for oil terminals rising in the future and more emphasis laid upon how to cost-effectively manage these terminals, the findings of this study may be quite useful in the area of efficient oil management.

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APPENDIX A

Data and Analysis

1. Simulation Output Summary (Multifactor ANOVA)

Design Point	Number of Tanks	Tank Size(1000 m^3)	Truck TBA(mnt)	Avg. Total Profit($1000 /Wk)
1	1	48	55	242.48
2	1	48	75	381.46
3	1	48	95	447.81
4	1	48	115	451.99
5	1	56	55	286.91
6	1	56	75	417.93
7	1	56	95	449.08
8	1	56	115	440.37
9	1	64	55	288.99
10	1	64	75	414.61
11	1	64	95	427.29
12	1	64	115	415.52
13	1	72	55	270.16
14	1	72	75	397.30
15	1	72	95	401.07
16	1	72	115	388.04
17	2	48	55	559.27
18	2	48	75	697.79
19	2	48	95	646.79
20	2	48	115	565.28
21	2	56	55	575.96
22	2	56	75	706.51
23	2	56	95	620.32
24	2	56	115	525.90
25	2	64	55	551.23
26	2	64	75	676.39
27	2	64	95	571.72

Design Point	Number of Tanks	Tank Size(1000 m^3)	Truck TBA(mnt)	Avg. Total Profit($1000 /Wk)
28	2	64	115	474.25
29	2	72	55	505.89
30	2	72	75	632.57
31	2	72	95	518.99
32	2	72	115	420.26
33	3	48	55	500.30
34	3	48	75	740.11
35	3	48	95	641.25
36	3	48	115	537.38
37	3	56	55	467.74
38	3	56	75	699.58
39	3	56	95	565.52
40	3	56	115	448.76
41	3	64	55	403.68
42	3	64	75	630.13
43	3	64	95	477.60
44	3	64	115	357.78
45	3	72	55	322.72
46	3	72	75	550.69
47	3	72	95	389.25
48	3	72	115	268.16
49	4	48	55	350.25
50	4	48	75	713.34
51	4	48	95	593.82
52	4	48	115	485.24
53	4	56	55	277.95
54	4	56	75	633.08
55	4	56	95	478.36
56	4	56	115	356.88

Design Point	Number of Tanks	Tank Size(1000 m^3)	Truck TBA(mnt)	Avg. Total Profit($1000 /Wk)
57	4	64	55	178.77
58	4	64	75	528.50
59	4	64	95	355.31
60	4	64	115	230.78
61	4	72	55	59.51
62	4	72	75	410.75
63	4	72	95	228.65
64	4	72	115	102.86

2. Tukey's Multifactor Interaction Result

Number of Tanks	Tank Size(1000 m^3)	Truck TBA(mnt)	Avg. Total Profit($1000 /Wk)	Delta	Group
4	72	55	59.51	-	1
4	72	115	102.86	43.35	2
4	64	55	178.77	75.91	3
4	72	95	228.65	49.88	4
4	64	115	230.78	2.12	4
1	48	55	242.48	11.71	4
3	72	115	268.16	25.68	5
1	72	55	270.16	2.00	5
4	56	55	277.95	7.79	5
1	56	55	286.91	8.96	5
1	64	55	288.99	2.07	5
3	72	55	322.72	33.73	6
4	48	55	350.25	27.53	7
4	64	95	355.31	5.06	7
4	56	115	356.88	1.57	7
3	64	115	357.78	0.89	7
1	48	75	381.46	23.68	7
1	72	115	388.04	6.58	7
3	72	95	389.25	1.21	7
1	72	75	397.30	8.05	7
1	72	95	401.07	3.78	7
3	64	55	403.68	2.61	7
4	72	75	410.75	7.07	7
1	64	75	414.61	3.86	7
1	64	115	415.52	0.91	7
1	56	75	417.93	2.41	7

Number of Tanks	Tank Size(1000 m^3)	Truck TBA(mnt)	Avg. Total Profit($1000 /Wk)	Delta	Group
2	72	115	420.26	2.33	7
1	64	95	427.29	7.03	7
1	56	115	440.37	13.07	7
1	48	95	447.81	7.45	7
3	56	115	448.76	0.94	7
1	56	95	449.08	0.33	7
1	48	115	451.99	2.91	7
3	56	55	467.74	15.75	7
2	64	115	474.25	6.52	7
3	64	95	477.60	3.35	7
4	56	95	478.36	0.76	7
4	48	115	485.24	6.88	7
3	48	55	500.30	15.06	7
2	72	55	505.89	5.59	7
2	72	95	518.99	13.10	7
2	56	115	525.90	6.92	7
4	64	75	528.50	2.60	7
3	48	115	537.38	8.87	7
3	72	75	550.69	13.31	7
2	64	55	551.23	0.54	7
2	48	55	559.27	8.04	7
2	48	115	565.28	6.00	7
3	56	95	565.52	0.25	7
2	64	95	571.72	6.20	7
2	56	55	575.96	4.23	7
4	48	95	593.82	17.86	7
2	56	95	620.32	26.50	8
3	64	75	630.13	9.82	8

Number of Tanks	Tank Size(1000 m^3)	Truck TBA(mnt)	Avg. Total Profit($1000 /Wk)	Delta	Group
2	72	75	632.57	2.43	8
4	56	75	633.08	0.51	8
3	48	95	641.25	8.17	8
2	48	95	646.79	5.54	8
2	**64**	75	**676.39**	**29.60**	**9**
2	**48**	75	**697.79**	**21.40**	**9**
3	**56**	**75**	**699.58**	**1.79**	**9**
2	**56**	75	**706.51**	**6.93**	**9**
4	**48**	75	**713.34**	**6.83**	**9**
3	**48**	75	**740.11**	**26.77**	**9**

APPENDIX B

Simulation Code (SIMAN)

```
PROJECT,      "Thesis","WALEED KHALID",,,Yes,Yes,Yes,Yes,No,No,Yes,No,No,Yes;

ATTRIBUTES:   TruckIn;

STORAGES:     Flow 1.Storage:
          Refill Tank 1.Storage;

VARIABLES:    Discount oil CM,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),45:
          Process truck2.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"),DATATYPE(Real):
          Oil_TBA,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),300:
          Tank fill time,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),15:
          Dispose 8.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Split Signal and Oil Entity.NumberOut Dup,CLEAR(Statistics),CATEGORY("Exclude"):
          Trucks balked.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck2.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck4.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck4.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          Dicount oil.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Truck WIP,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),0.0:
          Batch for truck1.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck2.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck4.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"),DATATYPE(Real):
          Batch for truck4.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck3.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Oil arrival at terminal.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Truck cost per minute,CLEAR(System),CATEGORY("User Specified-User
Specified"),DATATYPE(Real),1:
          Process_Truck1.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck2.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck4.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
          Truck_TBA,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),75:
          Create demand for tank 1 product.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Batch arrival at terminal.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck4.VACost,CLEAR(Statistics),CATEGORY("Exclude"):
          truck arrival at terminal.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Dispose 7.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Send truck to Q and mail to Signal.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
          Process_Truck1.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
          Fill tank.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Fill tank.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
          Dispose Signal.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck2.VACost,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck2.WaitCost,CLEAR(Statistics),CATEGORY("Exclude"):
          Batch size,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),0.0:
          Process truck4.WaitCost,CLEAR(Statistics),CATEGORY("Exclude"):
          Fill tank.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"),DATATYPE(Real):
          Batch for truck3.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck2.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Fill tank.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Send oil downstream.NumberOut False,CLEAR(Statistics),CATEGORY("Exclude"):
          Send oil downstream.NumberOut True,CLEAR(Statistics),CATEGORY("Exclude"):
          Split Signal and Oil Entity.NumberOut Orig,CLEAR(Statistics),CATEGORY("Exclude"):
          Process_Truck1.WaitCost,CLEAR(Statistics),CATEGORY("Exclude"):
          Fill tank.VACost,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck3.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"),DATATYPE(Real):
          Process_Truck1.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
          Process truck3.NumberIn,CLEAR(Statistics),CATEGORY("Exclude"):
          Batch arrival at terminal.NumberOut Dup,CLEAR(Statistics),CATEGORY("Exclude"):
```

Send truck to Q and mail to Signal.NumberOut Dup,CLEAR(Statistics),CATEGORY("Exclude"):
Process truck3.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
Process_Truck1.VATime,CLEAR(Statistics),CATEGORY("Exclude"):
Process_Truck1.WIP,CLEAR(System),CATEGORY("Exclude-Exclude"),DATATYPE(Real):
Truck fill time,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),75:
Match jop is completed so Dispose it.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Process truck3.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Fill tank.WaitTime,CLEAR(Statistics),CATEGORY("Exclude"):
Process truck4.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Truck capacity,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),40:
Dispose Mail.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Process truck3.VACost,CLEAR(Statistics),CATEGORY("Exclude"):
Process_Truck1.VACost,CLEAR(Statistics),CATEGORY("Exclude"):
Number of tanks,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),2:
Batch for truck2.NumberOut,CLEAR(Statistics),CATEGORY("Exclude"):
Regular oil CM,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),250:
Oil WIP,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),0.0:
Process truck3.WaitCost,CLEAR(Statistics),CATEGORY("Exclude"):
Cost per truck per trip,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),618:
Tank capacity,CLEAR(System),CATEGORY("User Specified-User Specified"),DATATYPE(Real),56:
Fill tank.WaitCost,CLEAR(Statistics),CATEGORY("Exclude");

QUEUES: Tank4_Truck4.Queue1,FIFO,,AUTOSTATS(Yes,,):
Tank4_Truck4.Queue2,FIFO,,AUTOSTATS(Yes,,):
Tank1_Truck1.Queue1,FIFO,,AUTOSTATS(Yes,,):
Tank1_Truck1.Queue2,FIFO,,AUTOSTATS(Yes,,):
Tank1.Queue,FIFO,,AUTOSTATS(Yes,,):
Batch for truck1.Queue,FIFO,,AUTOSTATS(Yes,,):
Truck Queue,FIFO,,AUTOSTATS(Yes,,):
Process truck2.Queue,FIFO,,AUTOSTATS(Yes,,):
Tank3_Truck3.Queue1,FIFO,,AUTOSTATS(Yes,,):
Tank3_Truck3.Queue2,FIFO,,AUTOSTATS(Yes,,):
Tank2.Queue,FIFO,,AUTOSTATS(Yes,,):
Batch for truck2.Queue,FIFO,,AUTOSTATS(Yes,,):
Process truck3.Queue,FIFO,,AUTOSTATS(Yes,,):
Batch for truck3.Queue,FIFO,,AUTOSTATS(Yes,,):
Seize Regulator 1.Queue,FIFO,,AUTOSTATS(Yes,,):
Tank2_Truck2.Queue1,FIFO,,AUTOSTATS(Yes,,):
Tank2_Truck2.Queue2,FIFO,,AUTOSTATS(Yes,,):
Tank3.Queue,FIFO,,AUTOSTATS(Yes,,):
Process_Truck1.Queue,FIFO,,AUTOSTATS(Yes,,):
Process truck4.Queue,FIFO,,AUTOSTATS(Yes,,):
Seize Regulator 2.Queue,FIFO,,AUTOSTATS(Yes,,):
Tank4.Queue,FIFO,,AUTOSTATS(Yes,,):
Batch for truck4.Queue,FIFO,,AUTOSTATS(Yes,,):
Fill tank.Queue,FIFO,,AUTOSTATS(Yes,,);

PICTURES: Picture.Airplane:
Picture.Green Ball:
Picture.Blue Page:
Picture.Telephone:
Picture.Blue Ball:
Picture.Yellow Page:
Picture.EMail:
Picture.Yellow Ball:
Picture.Bike:

```
        Picture.Report:
        Picture.Van:
        Picture.Widgets:
        Picture.Envelope:
        Picture.Fax:
        Picture.Truck:
        Picture.Person:
        Picture.Letter:
        Picture.Box:
        Picture.Woman:
        Picture.Package:
        Picture.Man:
        Picture.Diskette:
        Picture.Boat:
        Picture.Red Page:
        Picture.Ball:
        Picture.Green Page:
        Picture.Red Ball;

RESOURCES:    Pipe1,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
        Pipe2,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
        Pipe3,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
        Pipe4,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,):
        Tank 1.Regulator 1,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(No,,):
        Tank 1.Regulator 2,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(No,,):
        Terminal pipeline,Capacity(1),,,COST(0.0,0.0,0.0),CATEGORY(Resources),,AUTOSTATS(Yes,,);

TALLIES:    Process truck3.TotalTimePerEntity,,DATABASE(,"Total Time Per Entity","Process","Process
truck3"):
        Process_Truck1.TotalTimePerEntity,,DATABASE(,"Total Time Per
Entity","Process","Process_Truck1"):
        Process truck2.WaitTimePerEntity,,DATABASE(,"Wait Time Per Entity","Process","Process truck2"):
        Fill tank.VATimePerEntity,,DATABASE(,"VA Time Per Entity","Process","Fill tank"):
        Process_Truck1.VACostPerEntity,,DATABASE(,"VA Cost Per Entity","Process","Process_Truck1"):
        truck time in system,,DATABASE(,"Interval","User Specified","truck time in system"):
        Process_Truck1.WaitTimePerEntity,,DATABASE(,"Wait Time Per
Entity","Process","Process_Truck1"):
        Process truck3.VACostPerEntity,,DATABASE(,"VA Cost Per Entity","Process","Process truck3"):
        Process truck4.TotalCostPerEntity,,DATABASE(,"Total Cost Per Entity","Process","Process truck4"):
        Process truck2.TotalTimePerEntity,,DATABASE(,"Total Time Per Entity","Process","Process truck2"):
        Process truck4.WaitCostPerEntity,,DATABASE(,"Wait Cost Per Entity","Process","Process truck4"):
        Fill tank.WaitTimePerEntity,,DATABASE(,"Wait Time Per Entity","Process","Fill tank"):
        Process truck3.WaitTimePerEntity,,DATABASE(,"Wait Time Per Entity","Process","Process truck3"):
        Process truck4.VACostPerEntity,,DATABASE(,"VA Cost Per Entity","Process","Process truck4"):
        Process truck2.VATimePerEntity,,DATABASE(,"VA Time Per Entity","Process","Process truck2"):
        Fill tank.TotalCostPerEntity,,DATABASE(,"Total Cost Per Entity","Process","Fill tank"):
        Process truck3.TotalCostPerEntity,,DATABASE(,"Total Cost Per Entity","Process","Process truck3"):
        Process_Truck1.TotalCostPerEntity,,DATABASE(,"Total Cost Per
Entity","Process","Process_Truck1"):
        Process_Truck1.VATimePerEntity,,DATABASE(,"VA Time Per Entity","Process","Process_Truck1"):
        Process truck3.VATimePerEntity,,DATABASE(,"VA Time Per Entity","Process","Process truck3"):
        Process truck4.TotalTimePerEntity,,DATABASE(,"Total Time Per Entity","Process","Process truck4"):
        Process truck2.WaitCostPerEntity,,DATABASE(,"Wait Cost Per Entity","Process","Process truck2"):
        Process_Truck1.WaitCostPerEntity,,DATABASE(,"Wait Cost Per Entity","Process","Process_Truck1"):
        Fill tank.VACostPerEntity,,DATABASE(,"VA Cost Per Entity","Process","Fill tank"):
        Process truck4.WaitTimePerEntity,,DATABASE(,"Wait Time Per Entity","Process","Process truck4"):
        Process truck2.TotalCostPerEntity,,DATABASE(,"Total Cost Per Entity","Process","Process truck2"):
        Process truck4.VATimePerEntity,,DATABASE(,"VA Time Per Entity","Process","Process truck4"):
        Process truck3.WaitCostPerEntity,,DATABASE(,"Wait Cost Per Entity","Process","Process truck3"):
```

Fill tank.TotalTimePerEntity,,DATABASE(,"Total Time Per Entity","Process","Fill tank"):
Process truck2.VACostPerEntity,,DATABASE(,"VA Cost Per Entity","Process","Process truck2"):
Fill tank.WaitCostPerEntity,,DATABASE(,"Wait Cost Per Entity","Process","Fill tank");

DSTATS: ((Total Profit)/(MAX(dtpd(1),1))),ProfitPerMinute,"",DATABASE(,"Time Persistent","User Specified",
"ProfitPerMinute");

OUTPUTS: Fill tank.WaitTime + Fill tank.VATime,,Fill tank Total Accum Time,DATABASE(,"Total Accum Time","Process",
"Fill tank"):
Total truck usage cost,"Total truck usage cost.dat",TotalTruckUsage Cost,DATABASE(,"Output","User Specified",
"TotalTruckUsage Cost"):
Process_Truck1.WaitTime + Process_Truck1.VATime,,Process_Truck1 Total Accum Time,DATABASE(,"Total Accum Time",
"Process","Process_Truck1"):
Process truck2.WaitCost + Process truck2.VACost,,Process truck2 Total Accum Cost,DATABASE(,"Total Accum Cost",
"Process","Process truck2"):
Total truck balk cost,"Total truck balk cost.dat",Truck Balk Cost,DATABASE(,"Output","User Specified",
"Truck Balk Cost"):
Trucks balked.NumberOut,"TotalTruckBalk.dat",TotalTruckBalk,DATABASE(,"Output","User Specified","TotalTruckBalk"):
Process truck2.NumberIn,,Process truck2 Number In,DATABASE(,"Number In","Process","Process truck2"):
Process truck4.NumberIn,,Process truck4 Number In,DATABASE(,"Number In","Process","Process truck4"):
Process truck4.VATime,,Process truck4 Accum VA Time,DATABASE(,"Accum VA Time","Process","Process truck4"):
Process truck3.WaitTime + Process truck3.VATime,,Process truck3 Total Accum Time,DATABASE(,"Total Accum Time",
"Process","Process truck3"):
Process truck2.VATime,,Process truck2 Accum VA Time,DATABASE(,"Accum VA Time","Process","Process truck2"):
Process_Truck1.WaitCost + Process_Truck1.VACost,,Process_Truck1 Total Accum Cost,DATABASE(,"Total Accum Cost",
"Process","Process_Truck1"):
Process truck3.NumberOut,,Process truck3 Number Out,DATABASE(,"Number Out","Process","Process truck3"):
%Reg Oil Shipped,"",%RegOilShipped,DATABASE(,"Output","User Specified","%RegOilShipped"):
Process_Truck1.NumberIn,,Process_Truck1 Number In,DATABASE(,"Number In","Process","Process_Truck1"):
Process truck2.WaitTime,,Process truck2 Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Process truck2"):
Process truck4.WaitTime,,Process truck4 Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Process truck4"):
%TruckBalked,"%truck balked.dat",%truckBalked,DATABASE(,"Output","User Specified","%truckBalked"):
Total Lease Cost,"Total Lease Cost.dat",TotalLeaseCost,DATABASE(,"Output","User Specified","TotalLeaseCost"):
Total cost,"",Totalcost,DATABASE(,"Output","User Specified","Totalcost"):
Process truck4.VACost,,Process truck4 Accum VA Cost,DATABASE(,"Accum VA Cost","Process","Process truck4"):
Total truck cost in system,"Total truck cost in system.dat",Truckcostinsystem,DATABASE(,"Output","User Specified",
"Truckcostinsystem"):
Total Profit,"TotalProfit.dat",TotalProfit,DATABASE(,"Output","User Specified","TotalProfit"):

Process truck3.WaitCost + Process truck3.VACost,,Process truck3 Total Accum Cost,DATABASE(,"Total Accum Cost",
"Process","Process truck3"):
Process_Truck1.WaitTime,,Process_Truck1 Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Process_Truck1"):
Fill tank.NumberOut,,Fill tank Number Out,DATABASE(,"Number Out","Process","Fill tank"):
Fill tank.VATime,,Fill tank Accum VA Time,DATABASE(,"Accum VA Time","Process","Fill tank"):
Process truck2.VACost,,Process truck2 Accum VA Cost,DATABASE(,"Accum VA Cost","Process","Process truck2"):
Process truck2.WaitCost,,Process truck2 Accum Wait Cost,DATABASE(,"Accum Wait Cost","Process","Process truck2"):
Process truck4.WaitCost,,Process truck4 Accum Wait Cost,DATABASE(,"Accum Wait Cost","Process","Process truck4"):
Process truck4.WaitTime + Process truck4.VATime,,Process truck4 Total Accum Time,DATABASE(,"Total Accum Time",
"Process","Process truck4"):
Fill tank.NumberIn,,Fill tank Number In,DATABASE(,"Number In","Process","Fill tank"):
Process truck2.NumberOut,,Process truck2 Number Out,DATABASE(,"Number Out","Process","Process truck2"):
Process_Truck1.WaitCost,,Process_Truck1 Accum Wait Cost,DATABASE(,"Accum Wait Cost","Process","Process_Truck1"):
Fill tank.VACost,,Fill tank Accum VA Cost,DATABASE(,"Accum VA Cost","Process","Fill tank"):
Process_Truck1.NumberOut,,Process_Truck1 Number Out,DATABASE(,"Number Out","Process","Process_Truck1"):
Process truck3.NumberIn,,Process truck3 Number In,DATABASE(,"Number In","Process","Process truck3"):
Process truck4.WaitCost + Process truck4.VACost,,Process truck4 Total Accum Cost,DATABASE(,"Total Accum Cost",
"Process","Process truck4"):
Process truck3.VATime,,Process truck3 Accum VA Time,DATABASE(,"Accum VA Time","Process","Process truck3"):
Process_Truck1.VATime,,Process_Truck1 Accum VA Time,DATABASE(,"Accum VA Time","Process","Process_Truck1"):
Total truck cost per trip,"Total truck cost per trip.dat",truckcostpertrip,DATABASE(,"Output","User Specified",
"truckcostpertrip"):
TNUM(truck time in system),"Total truck shipped.dat",Total truck shipped,DATABASE(,"Output","User Specified",
"Total truck shipped"):
Process truck3.WaitTime,,Process truck3 Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Process truck3"):
Fill tank.WaitTime,,Fill tank Accum Wait Time,DATABASE(,"Accum Wait Time","Process","Fill tank"):
Process truck4.NumberOut,,Process truck4 Number Out,DATABASE(,"Number Out","Process","Process truck4"):
Process truck3.VACost,,Process truck3 Accum VA Cost,DATABASE(,"Accum VA Cost","Process","Process truck3"):
Process_Truck1.VACost,,Process_Truck1 Accum VA Cost,DATABASE(,"Accum VA Cost","Process","Process_Truck1"):
Process truck2.WaitTime + Process truck2.VATime,,Process truck2 Total Accum Time,DATABASE(,"Total Accum Time",
"Process","Process truck2"):
Fill tank.WaitCost + Fill tank.VACost,,Fill tank Total Accum Cost,DATABASE(,"Total Accum Cost","Process",
"Fill tank"):
Process truck3.WaitCost,,Process truck3 Accum Wait Cost,DATABASE(,"Accum Wait Cost","Process","Process truck3"):
Fill tank.WaitCost,,Fill tank Accum Wait Cost,DATABASE(,"Accum Wait Cost","Process","Fill tank");

REPLICATE, 10,,MinutesToBaseTime(1814400),Yes,Yes,MinutesToBaseTime(201600),,,24,Minutes,No,No,,
DATETIME("Mar 28, 2009 12:44:11"),Yes,No;

EXPRESSIONS: Total truck usage cost,DATATYPE(Native),Total truck cost in system+Total truck cost per trip:
Total truck balk cost,DATATYPE(Native),(Trucks balked.Numberout)*Cost per truck per trip:
Total regular oil CM,DATATYPE(Native),TNUM(truck time in system)*Truck capacity * Regular oil CM:
%Reg oil shipped,DATATYPE(Native),
(TNUM(truck time in system)*Truck capacity)/(Dicount oil.NumberOut + TNUM(truck time in system)*Truck capacity):
Total lease cost,DATATYPE(Native),0.01*dtpd(1)*Tank capacity * Number of tanks:
Total cost,DATATYPE(Native),Total lease cost + Total truck cost:
Total truck cost,DATATYPE(Native),Total truck balk cost + Total truck usage cost:
Total truck cost in system,DATATYPE(Native),
TNUM(truck time in system)*TAVG(truck time in system)*(Truck cost per minute):
Total profit,DATATYPE(Native),Total CM - Total cost:
%truck balked,DATATYPE(Native),(trucks balked.Numberout/MAX(EntitiesIn(Truck)/2,1)):
Total CM,DATATYPE(Native),Total discount oil CM + Total regular oil CM:
Total truck cost per trip,DATATYPE(Native),TNUM(truck time in system)*(cost per truck per trip):
Total discount oil CM,DATATYPE(Native),(Dicount oil.NumberOut)*Discount oil CM;

ENTITIES: Oil,Picture.Blue Ball,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
truck,Picture.Truck,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
Entity 1,Picture.Report,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,):
MESSAGE,Picture.Envelope,0.0,0.0,0.0,0.0,0.0,0.0,AUTOSTATS(Yes,,);

SETS: Tanks0,Tank1.Queue,Tank2.Queue,Tank3.Queue,Tank4.Queue:
PIPES,Pipe1,Pipe2,Pipe3,Pipe4:
Tank 1.Regulators,Tank 1.Regulator 1,Tank 1.Regulator 2;

TANKS: Tank 1,100.0,100,,,AUTOSTATS(Yes,,),REGULATOR(Tank 1.Regulator 1,10.0,Per Minute),REGULATOR(Tank 1.Regulator 2,10.0,Per Minute);

SENSORS: Sensor 2_detects when Tank 1 is full,LEVEL(Tank 1,Specific Level,100),Positive,
Sensor 2_detects when Tank 1 is full.Label,Enabled:
Sensor 1_detects when Tank 1 falls below 25,LEVEL(Tank 1,Specific Level,25),Negative,
Sensor 1_detects when Tank 1 falls below 25.Label,Enabled;

```
;
;
;      Model statements for module:  Create 1

69$         CREATE,
1,MinutesToBaseTime(0.0),truck:MinutesToBaseTime(expo(truck_TBA,2)):NEXT(70$);

70$         ASSIGN:       truck arrival at terminal.NumberOut=truck arrival at terminal.NumberOut +
1:NEXT(0$);
;
;
;     Model statements for module:  BasicProcess.Assign 3 (Record truck arriving time)
;
0$          ASSIGN:       TruckIn=Tnow:NEXT(1$);
;
;
;     Model statements for module:  BasicProcess.Separate 1 (Send truck to Q and mail to Signal)
;
1$          DUPLICATE,     100 - 0:
                     1,75$,0:NEXT(74$);

74$         ASSIGN:       Send truck to Q and mail to Signal.NumberOut Orig=
                     Send truck to Q and mail to Signal.NumberOut Orig + 1:NEXT(Truck awaiting tanks);

75$         ASSIGN:       Send truck to Q and mail to Signal.NumberOut Dup=
                     Send truck to Q and mail to Signal.NumberOut Dup + 1:NEXT(3$);

Truck awaiting tanks QUEUE,  Truck Queue,Number of tanks,2$:DETACH;

;
;
;     Model statements for module:  BasicProcess.Dispose 1 (Trucks balked)
;
2$          ASSIGN:       Trucks balked.NumberOut=Trucks balked.NumberOut + 1;
76$         DISPOSE:      Yes;
;
;
;     Model statements for module:  BasicProcess.Assign 5 (send mail to signal that truck has arrived)
;
3$          ASSIGN:       Entity.Type=MESSAGE:
                     Picture=Picture.Envelope:NEXT(4$);
;
;
;     Model statements for module:  BasicProcess.Decide 1 (which tank to send the truck ?)
;
4$          BRANCH,       1:
                     If,NQ(Tank1.Queue)>=truck capacity && (MR(Pipe1)-NR(Pipe1)>0) && NQ(Truck
Queue)>0,6$,Yes:
                     If,NQ(Tank2.Queue)>=truck capacity && (MR(Pipe2)-NR(Pipe2)>0) && NQ(Truck
Queue)>0,17$,Yes:
                     If,NQ(Tank3.Queue)>=truck capacity && (MR(Pipe3)-NR(Pipe3)>0) && NQ(Truck
Queue)>0,24$,Yes:
                     If,NQ(Tank4.Queue)>=truck capacity && (MR(Pipe4)-NR(Pipe4)>0) && NQ(Truck
Queue)>0,31$,Yes:
                     Else,5$,Yes;
;
;
```

```
;     Model statements for module:  BasicProcess.Dispose 3 (Dispose Mail)
;
5$          ASSIGN:       Dispose Mail.NumberOut=Dispose Mail.NumberOut + 1;
79$         DISPOSE:      Yes;


;
;
;     Model statements for module:  AdvancedProcess.Signal 3 (Signal 1)
;
6$          SIGNAL:       1,Truck capacity:NEXT(Release truck for tank1);

Release truck for tank1 REMOVE: 1,truck queue,11$:NEXT(7$);
;
;
;     Model statements for module:  BasicProcess.Dispose 4 (Dispose Signal)
;
7$          ASSIGN:       Dispose Signal.NumberOut=Dispose Signal.NumberOut + 1;
80$         DISPOSE:      Yes;
;
;
;     Model statements for module:  AdvancedProcess.Match 2 (Tank1_Truck1)
;
8$          QUEUE,        Tank1_Truck1.Queue1:DETACH;
11$         QUEUE,        Tank1_Truck1.Queue2:DETACH;
          MATCH:       8$,16$:
                    11$,13$;
;
;
;     Model statements for module:  BasicProcess.Process 2 (Process_Truck1)
;
13$         ASSIGN:       Process_Truck1.NumberIn=Process_Truck1.NumberIn + 1:
                    Process_Truck1.WIP=Process_Truck1.WIP+1;
110$        STACK,        1:Save:NEXT(84$);

84$         QUEUE,        Process_Truck1.Queue;
83$         SEIZE,        2,VA:
                    Pipe1,1:NEXT(82$);

82$         DELAY:        Truck fill time,,VA:NEXT(125$);

125$        ASSIGN:       Process_Truck1.WaitTime=Process_Truck1.WaitTime + Diff.WaitTime;
89$         TALLY:        Process_Truck1.WaitTimePerEntity,Diff.WaitTime,1;
126$        ASSIGN:       Process_Truck1.WaitCost=Process_Truck1.WaitCost + Diff.WaitCost;
87$         TALLY:        Process_Truck1.WaitCostPerEntity,Diff.WaitCost,1;
91$         TALLY:        Process_Truck1.TotalTimePerEntity,Diff.StartTime,1;
92$         TALLY:        Process_Truck1.TotalCostPerEntity,
                    Diff.WaitCost + Diff.VACost + Diff.NVACost + Diff.TranCost + Diff.OtherCost,1;
115$        ASSIGN:       Process_Truck1.VATime=Process_Truck1.VATime + Diff.VATime;
116$        TALLY:        Process_Truck1.VATimePerEntity,Diff.VATime,1;
120$        ASSIGN:       Process_Truck1.VACost=Process_Truck1.VACost + Diff.VACost;
117$        TALLY:        Process_Truck1.VACostPerEntity,Diff.VACost,1;
81$         RELEASE:      Pipe1,1;
130$        STACK,        1:Destroy:NEXT(129$);

129$        ASSIGN:       Process_Truck1.NumberOut=Process_Truck1.NumberOut + 1:
                    Process_Truck1.WIP=Process_Truck1.WIP-1:NEXT(14$);
```

```
;
;
;     Model statements for module:  BasicProcess.Record 1 (Record truck time in system)
;
14$          TALLY:         truck time in system,INT(TruckIn),1:NEXT(15$);
;
;
;     Model statements for module:  BasicProcess.Assign 6 (Send mail to truck in Q and Dec oil WIP)
;
15$          ASSIGN:        Oil WIP=Oil WIP-Truck capacity:
                            Entity.Type=MESSAGE:
                            Picture=Picture.Envelope:NEXT(4$);
;
;
;     Model statements for module:  BasicProcess.Dispose 5 (Match jop is completed so Dispose it)
;
16$          ASSIGN:        Match jop is completed so Dispose it.NumberOut=Match jop is completed so Dispose
it.NumberOut + 1;
132$          DISPOSE:       Yes;
;
;
;     Model statements for module:  AdvancedProcess.Signal 4 (Signal 2)
;
17$          SIGNAL:        2,Truck capacity:NEXT(Release truck for tank2);

Release truck for tank2 REMOVE: 1,Truck Queue,21$:NEXT(7$);
;
;
;     Model statements for module:  AdvancedProcess.Match 3 (Tank2_Truck2)
;
18$          QUEUE,         Tank2_Truck2.Queue1:DETACH;
21$          QUEUE,         Tank2_Truck2.Queue2:DETACH;
           MATCH:        18$,16$:
                            21$,23$;
;
;
;     Model statements for module:  BasicProcess.Process 3 (Process truck2)
;
23$          ASSIGN:        Process truck2.NumberIn=Process truck2.NumberIn + 1:
                            Process truck2.WIP=Process truck2.WIP+1;
162$          STACK,         1:Save:NEXT(136$);

136$          QUEUE,         Process truck2.Queue;
135$          SEIZE,        2,VA:
                            Pipe2,1:NEXT(134$);

134$          DELAY:         Truck fill time,,VA:NEXT(177$);

177$          ASSIGN:        Process truck2.WaitTime=Process truck2.WaitTime + Diff.WaitTime;
141$          TALLY:         Process truck2.WaitTimePerEntity,Diff.WaitTime,1;
178$          ASSIGN:        Process truck2.WaitCost=Process truck2.WaitCost + Diff.WaitCost;
139$          TALLY:         Process truck2.WaitCostPerEntity,Diff.WaitCost,1;
143$          TALLY:         Process truck2.TotalTimePerEntity,Diff.StartTime,1;
144$          TALLY:         Process truck2.TotalCostPerEntity,
                            Diff.WaitCost + Diff.VACost + Diff.NVACost + Diff.TranCost + Diff.OtherCost,1;
167$          ASSIGN:        Process truck2.VATime=Process truck2.VATime + Diff.VATime;
168$          TALLY:         Process truck2.VATimePerEntity,Diff.VATime,1;
172$          ASSIGN:        Process truck2.VACost=Process truck2.VACost + Diff.VACost;
```

```
169$      TALLY:      Process truck2.VACostPerEntity,Diff.VACost,1;
133$      RELEASE:      Pipe2,1;
182$      STACK,      1:Destroy:NEXT(181$);

181$      ASSIGN:      Process truck2.NumberOut=Process truck2.NumberOut + 1:
                 Process truck2.WIP=Process truck2.WIP-1:NEXT(14$);
;
;
;   Model statements for module:  AdvancedProcess.Signal 5 (Signal 3)
;
24$      SIGNAL:      3,Truck capacity:NEXT(Release truck for tank3);

Release truck for tank3 REMOVE: 1,Truck Queue,28$:NEXT(7$);
;
;
;   Model statements for module:  AdvancedProcess.Match 4 (Tank3_Truck3)
;
25$      QUEUE,      Tank3_Truck3.Queue1:DETACH;
28$      QUEUE,      Tank3_Truck3.Queue2:DETACH;
         MATCH:      25$,16$:
                 28$,30$;
;
;
;   Model statements for module:  BasicProcess.Process 4 (Process truck3)
;
30$      ASSIGN:      Process truck3.NumberIn=Process truck3.NumberIn + 1:
                 Process truck3.WIP=Process truck3.WIP+1;
213$      STACK,      1:Save:NEXT(187$);

187$      QUEUE,      Process truck3.Queue;
186$      SEIZE,      2,VA:
                 Pipe3,1:NEXT(185$);

185$      DELAY:      Truck fill time,,VA:NEXT(228$);

228$      ASSIGN:      Process truck3.WaitTime=Process truck3.WaitTime + Diff.WaitTime;
192$      TALLY:      Process truck3.WaitTimePerEntity,Diff.WaitTime,1;
229$      ASSIGN:      Process truck3.WaitCost=Process truck3.WaitCost + Diff.WaitCost;
190$      TALLY:      Process truck3.WaitCostPerEntity,Diff.WaitCost,1;
194$      TALLY:      Process truck3.TotalTimePerEntity,Diff.StartTime,1;
195$      TALLY:      Process truck3.TotalCostPerEntity,
                 Diff.WaitCost + Diff.VACost + Diff.NVACost + Diff.TranCost + Diff.OtherCost,1;
218$      ASSIGN:      Process truck3.VATime=Process truck3.VATime + Diff.VATime;
219$      TALLY:      Process truck3.VATimePerEntity,Diff.VATime,1;
223$      ASSIGN:      Process truck3.VACost=Process truck3.VACost + Diff.VACost;
220$      TALLY:      Process truck3.VACostPerEntity,Diff.VACost,1;
184$      RELEASE:      Pipe3,1;
233$      STACK,      1:Destroy:NEXT(232$);

232$      ASSIGN:      Process truck3.NumberOut=Process truck3.NumberOut + 1:
                 Process truck3.WIP=Process truck3.WIP-1:NEXT(14$);


;
;
;   Model statements for module:  AdvancedProcess.Signal 7 (Signal 4)
;
31$      SIGNAL:      4,Truck capacity:NEXT(Release truck for tank4);
```

```
Release truck for tank4 REMOVE: 1,Truck Queue,35$:NEXT(7$);
;
;
;     Model statements for module:  AdvancedProcess.Match 5 (Tank4_Truck4)
;
32$          QUEUE,        Tank4_Truck4.Queue1:DETACH;
35$          QUEUE,        Tank4_Truck4.Queue2:DETACH;
           MATCH:        32$,16$:
                     35$,37$;
;
;
;     Model statements for module:  BasicProcess.Process 5 (Process truck4)
;
37$          ASSIGN:       Process truck4.NumberIn=Process truck4.NumberIn + 1:
                     Process truck4.WIP=Process truck4.WIP+1;
264$         STACK,        1:Save:NEXT(238$);

238$         QUEUE,        Process truck4.Queue;
237$         SEIZE,        2,VA:
                     Pipe4,1:NEXT(236$);

236$         DELAY:        Truck fill time,,VA:NEXT(279$);

279$         ASSIGN:       Process truck4.WaitTime=Process truck4.WaitTime + Diff.WaitTime;
243$         TALLY:        Process truck4.WaitTimePerEntity,Diff.WaitTime,1;
280$         ASSIGN:       Process truck4.WaitCost=Process truck4.WaitCost + Diff.WaitCost;
241$         TALLY:        Process truck4.WaitCostPerEntity,Diff.WaitCost,1;
245$         TALLY:        Process truck4.TotalTimePerEntity,Diff.StartTime,1;
246$         TALLY:        Process truck4.TotalCostPerEntity,
                     Diff.WaitCost + Diff.VACost + Diff.NVACost + Diff.TranCost + Diff.OtherCost,1;
269$         ASSIGN:       Process truck4.VATime=Process truck4.VATime + Diff.VATime;
270$         TALLY:        Process truck4.VATimePerEntity,Diff.VATime,1;
274$         ASSIGN:       Process truck4.VACost=Process truck4.VACost + Diff.VACost;
271$         TALLY:        Process truck4.VACostPerEntity,Diff.VACost,1;
235$         RELEASE:      Pipe4,1;
284$         STACK,        1:Destroy:NEXT(283$);

283$         ASSIGN:       Process truck4.NumberOut=Process truck4.NumberOut + 1:
                     Process truck4.WIP=Process truck4.WIP-1:NEXT(14$);
;
;
;     Model statements for module:  BasicProcess.Create 2 (Oil arrival at terminal)
;

286$         CREATE,
1,MinutesToBaseTime(0.0),Oil:MinutesToBaseTime(expo(Oil_TBA,1)):NEXT(287$);

287$         ASSIGN:       Oil arrival at terminal.NumberOut=Oil arrival at terminal.NumberOut + 1:NEXT(38$);
;
;
;     Model statements for module:  BasicProcess.Assign 7 (Assign batch size)
;
38$          ASSIGN:       Batch size=discrete(0.33,6,0.67,8,1.0,10,3):NEXT(39$);
;
;
;     Model statements for module:  BasicProcess.Separate 2 (Batch arrival at terminal)
;
39$          DUPLICATE,    100 - 0:
```

```
                  Batch size-1,292$,0:NEXT(291$);

291$      ASSIGN:     Batch arrival at terminal.NumberOut Orig=Batch arrival at terminal.NumberOut Orig +
1:NEXT(40$);

292$      ASSIGN:     Batch arrival at terminal.NumberOut Dup=Batch arrival at terminal.NumberOut Dup +
1:NEXT(40$);
;
;
;     Model statements for module:  BasicProcess.Decide 2 (Send oil downstream)
;
40$       BRANCH,     1:
                  If,Oil WIP>=(Number of tanks*Tank capacity),293$,Yes:
                  Else,294$,Yes;
293$      ASSIGN:     Send oil downstream.NumberOut True=Send oil downstream.NumberOut True +
1:NEXT(41$);

294$      ASSIGN:     Send oil downstream.NumberOut False=Send oil downstream.NumberOut False +
1:NEXT(42$);
;
;
;     Model statements for module:  BasicProcess.Dispose 6 (Dicount oil)
;
41$       ASSIGN:     Dicount oil.NumberOut=Dicount oil.NumberOut + 1;
295$      DISPOSE:    Yes;
;
;
;     Model statements for module:  BasicProcess.Assign 8 (Increase oil WIP)
;
42$       ASSIGN:     Oil WIP=Oil WIP+1:NEXT(43$);
;
;
;     Model statements for module:  BasicProcess.Process 6 (Fill tank)
;
43$       ASSIGN:     Fill tank.NumberIn=Fill tank.NumberIn + 1:
                  Fill tank.WIP=Fill tank.WIP+1;
325$      STACK,      1:Save:NEXT(299$);

299$      QUEUE,      Fill tank.Queue;
298$      SEIZE,      2,VA:
                  Terminal pipeline,1:NEXT(297$);

297$      DELAY:      Tank fill time,,VA:NEXT(340$);

340$      ASSIGN:     Fill tank.WaitTime=Fill tank.WaitTime + Diff.WaitTime;
304$      TALLY:      Fill tank.WaitTimePerEntity,Diff.WaitTime,1;
341$      ASSIGN:     Fill tank.WaitCost=Fill tank.WaitCost + Diff.WaitCost;
302$      TALLY:      Fill tank.WaitCostPerEntity,Diff.WaitCost,1;
306$      TALLY:      Fill tank.TotalTimePerEntity,Diff.StartTime,1;
307$      TALLY:      Fill tank.TotalCostPerEntity,
                  Diff.WaitCost + Diff.VACost + Diff.NVACost + Diff.TranCost + Diff.OtherCost,1;
330$      ASSIGN:     Fill tank.VATime=Fill tank.VATime + Diff.VATime;
331$      TALLY:      Fill tank.VATimePerEntity,Diff.VATime,1;
335$      ASSIGN:     Fill tank.VACost=Fill tank.VACost + Diff.VACost;
332$      TALLY:      Fill tank.VACostPerEntity,Diff.VACost,1;
296$      RELEASE:    Terminal pipeline,1;
345$      STACK,      1:Destroy:NEXT(344$);
```

```
344$        ASSIGN:      Fill tank.NumberOut=Fill tank.NumberOut + 1:
                    Fill tank.WIP=Fill tank.WIP-1:NEXT(44$);
;
;
;     Model statements for module:  BasicProcess.Separate 3 (Split Signal and Oil Entity)
;
44$         DUPLICATE,     100 - 0:
                    1,349$,0:NEXT(348$);

348$        ASSIGN:      Split Signal and Oil Entity.NumberOut Orig=Split Signal and Oil Entity.NumberOut
Orig + 1:NEXT(59$);

349$        ASSIGN:      Split Signal and Oil Entity.NumberOut Dup=Split Signal and Oil Entity.NumberOut
Dup + 1:NEXT(58$);

59$         FINDJ,       1,Number of tanks:MIN(aint(NQ(TANKS0(J))/Truck
capacity)+NR(PIPES(J))):NEXT(45$);
;
;
;     Model statements for module:  BasicProcess.Decide 3 (Which tank to fill)
;
45$         BRANCH,      1:
                    If,J==1,49$,Yes:
                    If,J==2,52$,Yes:
                    If,J==3,55$,Yes:
                    Else,46$,Yes;
;
;
;     Model statements for module:  AdvancedProcess.Hold 1 (Tank4)
;
46$         QUEUE,       Tank4.Queue;
          WAIT:       4,Truck capacity:NEXT(48$);
;
;
;     Model statements for module:  BasicProcess.Batch 1 (Batch for truck4)
;
48$         QUEUE,       Batch for truck4.Queue;
352$        GROUP,       ,Permanent:Truck capacity,Last:NEXT(353$);

353$        ASSIGN:      Batch for truck4.NumberOut=Batch for truck4.NumberOut + 1:NEXT(32$);
;
;
;     Model statements for module:  AdvancedProcess.Hold 2 (Tank1)
;
49$         QUEUE,       Tank1.Queue;
          WAIT:       1,Truck capacity:NEXT(51$);
;
;
;     Model statements for module:  BasicProcess.Batch 2 (Batch for truck1)
;
51$         QUEUE,       Batch for truck1.Queue;
354$        GROUP,       ,Permanent:Truck capacity,Last:NEXT(355$);

355$        ASSIGN:      Batch for truck1.NumberOut=Batch for truck1.NumberOut + 1:NEXT(8$);
;
;
;     Model statements for module:  AdvancedProcess.Hold 3 (Tank2)
;
```

```
52$          QUEUE,        Tank2.Queue;
          WAIT:          2,Truck capacity:NEXT(54$);
;
;
;     Model statements for module:  BasicProcess.Batch 3 (Batch for truck2)
;
54$          QUEUE,        Batch for truck2.Queue;
356$         GROUP,        ,Permanent:Truck capacity,Last:NEXT(357$);

357$         ASSIGN:       Batch for truck2.NumberOut=Batch for truck2.NumberOut + 1:NEXT(18$);
;
;
;     Model statements for module:  AdvancedProcess.Hold 4 (Tank3)
;
55$          QUEUE,        Tank3.Queue;
          WAIT:          3,Truck capacity:NEXT(57$);
;
;
;     Model statements for module:  BasicProcess.Batch 4 (Batch for truck3)
;
57$          QUEUE,        Batch for truck3.Queue;
358$         GROUP,        ,Permanent:Truck capacity,Last:NEXT(359$);

359$         ASSIGN:       Batch for truck3.NumberOut=Batch for truck3.NumberOut + 1:NEXT(25$);
;
;
;     Model statements for module:  BasicProcess.Assign 9 (Send mail to signal that oil has arrived)
;
58$          ASSIGN:       Entity.Type=MESSAGE:
                        Picture=Picture.Envelope:NEXT(4$);
;
;
;     Model statements for module:  FlowProcess.Tank 1 (Tank 1)
;
;
;
;     Model statements for module:  FlowProcess.Sensor 1 (Sensor 1_detects when Tank 1 falls below 25)
;
Sensor 1_detects when Tank 1 falls below 25.Label DELAY: 0.0,,Other;
367$         DELAY:        0.0,,Other:NEXT(366$);
366$         DELAY:        0.0,,Other:NEXT(64$);
;
;
;     Model statements for module:  FlowProcess.Seize Regulator 2 (Seize Regulator 2)
;
64$          QUEUE,        Seize Regulator 2.Queue;
368$         SEIZE,        2,Other:
                        Tank 1.Regulator 2,1:NEXT(65$);
;
;
;     Model statements for module:  FlowProcess.Flow 2 (Refill Tank 1)
;
65$          FLOW:         Add(Tank 1.Regulator 2),,,1,2,VA,,Refill Tank 1.Storage:NEXT(66$);
;
;
;     Model statements for module:  FlowProcess.Release Regulator 2 (Release Regulator 2)
;
66$          RELEASE:      Tank 1.Regulator 2,1:NEXT(67$);
```

```
;
;
;    Model statements for module:  BasicProcess.Dispose 7 (Dispose 7)
;
67$          ASSIGN:        Dispose 7.NumberOut=Dispose 7.NumberOut + 1;
369$         DISPOSE:       No;
;
;
;    Model statements for module:  BasicProcess.Create 3 (Create demand for tank 1 product)
;

370$         CREATE,        1,HoursToBaseTime(0.0),Entity 1:HoursToBaseTime(EXPO(1)):NEXT(371$);

371$         ASSIGN:        Create demand for tank 1 product.NumberOut=Create demand for tank 1
product.NumberOut + 1:NEXT(62$);
;
;
;    Model statements for module:  FlowProcess.Seize Regulator 1 (Seize Regulator 1)
;
62$          QUEUE,         Seize Regulator 1.Queue;
374$         SEIZE,         2,Other:
                     Tank 1.Regulator 1,1:NEXT(61$);
;
;
;    Model statements for module:  FlowProcess.Flow 1 (Flow 1)
;
61$          FLOW:          Remove(Tank 1.Regulator 1),TRIA( 4, 6, 8),,,2,VA,,Flow 1.Storage:NEXT(63$);
;
;
;    Model statements for module:  FlowProcess.Release Regulator 1 (Release Regulator 1)
;
63$          RELEASE:       Tank 1.Regulator 1,1:NEXT(68$);
;
;
;    Model statements for module:  BasicProcess.Dispose 8 (Dispose 8)
;
68$          ASSIGN:        Dispose 8.NumberOut=Dispose 8.NumberOut + 1;
375$         DISPOSE:       No;
;
;
;    Model statements for module:  FlowProcess.Sensor 2 (Sensor 2_detects when Tank 1 is full)
;
Sensor 2_detects when Tank 1 is full.Label DELAY: 0.0,,Other:NEXT(379$);

379$         SIGNAL:        1;
380$         DELAY:         0.0,,Other:NEXT(378$);

378$         DELAY:         0.0,,Other:NEXT(376$);

376$         DISPOSE:       No;
```

APPENDIX C

I-LOG Program Outputs

1. In Volume through Refinery on Truck (Solution 3)

	Small Truck	Big Truck		Small Truck	Big Truck
< A, I, B >	300	0	< E, I, A >	123	0
< A, I, C >	250	0	< E, I, B >	234	0
< A, I, D >	310	0	< E, I, C >	143	0
< A, I, E >	145	40	< E, I, D >	78	0
< A, I, F >	300	0	< E, I, F >	107	0
< A, I, G >	125	0	< E, I, G >	98	0
< A, I, H >	250	0	< E, I, H >	115	0
< A, J, B >	0	0	< E, J, A >	0	0
< A, J, C >	0	0	< E, J, B >	0	0
< A, J, D >	0	0	< E, J, C >	0	0
< A, J, E >	0	0	< E, J, D >	0	0
< A, J, F >	0	0	< E, J, F >	0	0
< A, J, G >	0	0	< E, J, G >	0	0
< A, J, H >	0	0	< E, J, H >	0	0
< B, I, A >	185	0	< F, I, A >	201	0
< B, I, C >	200	0	< F, I, B >	157	0
< B, I, D >	221	0	< F, I, C >	169	0
< B, I, E >	263	0	< F, I, D >	212	0
< B, I, F >	197	0	< F, I, E >	104	0
< B, I, G >	220	0	< F, I, G >	201	0
< B, I, H >	180	0	< F, I, H >	99	0
< B, J, A >	0	0	< F, J, A >	0	0
< B, J, C >	0	0	< F, J, B >	0	0
< B, J, D >	0	0	< F, J, C >	0	0
< B, J, E >	0	0	< F, J, D >	0	0
< B, J, F >	0	0	< F, J, E >	0	0
< B, J, G >	0	0	< F, J, G >	0	0
< B, J, H >	0	0	< F, J, H >	0	0
< C, I, A >	143	0	< G, I, A >	215	0
< C, I, B >	178	0	< G, I, B >	147	0
< C, I, D >	258	0	< G, I, C >	149	0
< C, I, E >	221	0	< G, I, D >	190	0
< C, I, F >	106	0	< G, I, E >	114	0
< C, I, G >	190	0	< G, I, F >	210	0
< C, I, H >	110	0	< G, I, H >	199	0
< C, J, A >	0	0	< G, J, A >	0	0
< C, J, B >	0	0	< G, J, B >	0	0
< C, J, D >	0	0	< G, J, C >	0	0
< C, J, E >	0	0	< G, J, D >	0	0
< C, J, F >	0	0	< G, J, E >	0	0
< C, J, G >	0	0	< G, J, F >	0	0
< C, J, H >	0	0	< G, J, H >	0	0
< D, I, A >	75	0	< H, I, A >	181	0
< D, I, B >	135	0	< H, I, B >	137	0
< D, I, C >	245	0	< H, I, C >	139	0

	Small Truck	Big Truck		Small Truck	Big Truck
< D, I, E >	283	0	< H, I, D >	180	0
< D, I, F >	155	0	< H, I, E >	124	0
< D, I, G >	260	0	< H, I, F >	160	0
< D, I, H >	165	0	< H, I, G >	221	0
< D, J, A >	0	0	< H, J, A >	0	0
< D, J, B >	0	0	< H, J, B >	0	0
< D, J, C >	0	0	< H, J, C >	0	0
< D, J, E >	0	0	< H, J, D >	0	0
< D, J, F >	0	0	< H, J, E >	0	0
< D, J, G >	0	0	< H, J, F >	0	0
< D, J, H >	0	0	< H, J, G >	0	0

2. Values for out Volume through Refinery on Truck (Solution 3)

	Small Truck	Big Truck		Small Truck	Big Truck
< A, I, B >	300	0	< E, I, A >	123	0
< A, I, C >	250	0	< E, I, B >	234	0
< A, I, D >	350	0	< E, I, C >	143	0
< A, I, E >	145	0	< E, I, D >	78	0
< A, I, F >	300	0	< E, I, F >	107	0
< A, I, G >	125	0	< E, I, G >	98	0
< A, I, H >	250	0	< E, I, H >	115	0
< A, J, B >	0	0	< E, J, A >	0	0
< A, J, C >	0	0	< E, J, B >	0	0
< A, J, D >	0	0	< E, J, C >	0	0
< A, J, E >	0	0	< E, J, D >	0	0
< A, J, F >	0	0	< E, J, F >	0	0
< A, J, G >	0	0	< E, J, G >	0	0
< A, J, H >	0	0	< E, J, H >	0	0
< B, I, A >	185	0	< F, I, A >	201	40
< B, I, C >	200	0	< F, I, B >	157	0
< B, I, D >	221	0	< F, I, C >	169	0
< B, I, E >	263	0	< F, I, D >	212	0
< B, I, F >	197	0	< F, I, E >	104	0
< B, I, G >	220	0	< F, I, G >	201	0
< B, I, H >	180	0	< F, I, H >	99	0
< B, J, A >	0	0	< F, J, A >	0	0
< B, J, C >	0	0	< F, J, B >	0	0
< B, J, D >	0	0	< F, J, C >	0	0
< B, J, E >	0	0	< F, J, D >	0	0
< B, J, F >	0	0	< F, J, E >	0	0
< B, J, G >	0	0	< F, J, G >	0	0
< B, J, H >	0	0	< F, J, H >	0	0
< C, I, A >	143	0	< G, I, A >	215	0
< C, I, B >	178	0	< G, I, B >	147	0
< C, I, D >	258	0	< G, I, C >	149	0

	Small Truck	Big Truck		Small Truck	Big Truck
< C, I, E >	221	0	< G, I, D >	190	0
< C, I, F >	106	0	< G, I, E >	114	0
< C, I, G >	190	0	< G, I, F >	210	0
< C, I, H >	110	0	< G, I, H >	199	0
< C, J, A >	0	0	< G, J, A >	0	0
< C, J, B >	0	0	< G, J, B >	0	0
< C, J, D >	0	0	< G, J, C >	0	0
< C, J, E >	0	0	< G, J, D >	0	0
< C, J, F >	0	0	< G, J, E >	0	0
< C, J, G >	0	0	< G, J, F >	0	0
< C, J, H >	0	0	< G, J, H >	0	0
< D, I, A >	75	0	< H, I, A >	141	0
< D, I, B >	135	0	< H, I, B >	137	0
< D, I, C >	245	0	< H, I, C >	139	0
< D, I, E >	283	0	< H, I, D >	180	0
< D, I, F >	155	0	< H, I, E >	124	0
< D, I, G >	260	0	< H, I, F >	160	0
< D, I, H >	165	0	< H, I, G >	221	0
< D, J, A >	0	0	< H, J, A >	0	0
< D, J, B >	0	0	< H, J, B >	0	0
< D, J, C >	0	0	< H, J, C >	0	0
< D, J, E >	0	0	< H, J, D >	0	0
< D, J, F >	0	0	< H, J, E >	0	0
< D, J, G >	0	0	< H, J, F >	0	0
< D, J, H >	0	0	< H, J, G >	0	0

APPENDIX D

I-LOG Program Source Code

1. The Mathematical Models' Code

```
/***********************************************
 * OPL 4.2 OIL TRANSPORTATION Problem
 * Auther: WALEED KHALID
 * Creation Date: Thur July 10:15:40 2010
************************************************/

{string} Location = ...;
{string} TruckTypes = ...;

{string} depots = ...;
{string} refineries = ...;

tuple depotInfo {
  int     minDepTime; // Earliest departure time at depot
  int     maxArrTime; // Latest arrive time at depot
};

depotInfo depot[depots] = ...;

// Make sure the data is consistent: latest arrive time >= earlist departure time
assert forall(s in depots) depot[s].maxArrTime > depot[s].minDepTime;

tuple TruckTypeInfo {
  int   capacity;
  int   costPerMile;
  int   milesPerHour; //speed
}

TruckTypeInfo truckType[TruckTypes] = ...;
int loadTime[refineries][TruckTypes] = ...; // in minutes; loadTime = unloadTime

tuple RouteInfo {
  string   depot;
```

```
  string   refinery;
  int      distance;  // in miles
}
{RouteInfo} routes = ...;

// The following assertion is to make sure that the depot
// in each route is indeed in the set of depots.
assert forall(r in routes : r.depot not in depots) 1 == 0;

// The following assertion is to make sure that the refinery
// in each route are indeed in the set of refineries.
assert forall(r in routes : r.refinery not in refineries) 1 == 0;

tuple Triples {
  string origin;
  string refinery;
  string destination;
}

{Triples} triples =  // feasible pathes from depots to depots via one refinery
{<r1.depot,r1.refinery,r2.depot> | r1,r2 in routes : r1 != r2 && r1.refinery == r2.refinery};

tuple Shipment {
  string   origin;
  string   destination;
  int      totalVolume;
}
{Shipment} shipments = ...;

// The following assertion is to make sure that the origin
// of each shipment is indeed in the set of depots.
assert forall(s in shipments : s.origin not in depots) 1 == 0;

// The following assertion is to make sure that the destination
// of each shipment is indeed in the set of depots.
assert forall(s in shipments : s.destination not in depots) 1 == 0;
```

```
int possibleTruckOnRoute[routes][TruckTypes];

// the earlist unloading time at a depot for each type of trucks
int earliestUnloadingTime[routes][TruckTypes];
// the latest loading time at a refinery for each type of trucks
int latestLoadingTime[routes][TruckTypes];

// Compute possible truck types that can be assigned on a route
execute INITIALIZE {
  for(var r in routes)
    for(var t in TruckTypes) {
      earliestUnloadingTime[r][t] = Math.ceil(loadTime[r.refinery][t] +
depot[r.depot].minDepTime + 60*r.distance/truckType[t].milesPerHour);
      latestLoadingTime[r][t] = Math.floor(depot[r.depot].maxArrTime -
loadTime[r.refinery][t] - 60*r.distance/truckType[t].milesPerHour);
      // A type of truck can be assigned on a route only if it can make it to the refinery and
back
      //  before the max arrival time at the depot.
      if ( earliestUnloadingTime[r][t] < latestLoadingTime[r][t]) {
        possibleTruckOnRoute[r][t] = 1;
      }
      else {
        possibleTruckOnRoute[r][t] = 0;
      }
    }
}

int maxTrucks = 100;  // Maximum # of trucks for each type on a route

// Maximum Volume of goods that can be handled
// on each path for each type of trucks
int maxVolume = 5000;

dvar int+ truckOnRoute[routes][TruckTypes] in 0..maxTrucks;

// This represents the volumes shipped out from each refinery
// by each type of trucks on each triple
```

```
// The volumes are distinguished by trucktypes because trucks of different types
// arrive at a refinery at different times and the timing is used in defining
// the constraints for volume availability for the trucks leaving the refinery.
dvar int+ outVolumeThroughRefineryOnTruck[triples][TruckTypes] in 0..maxVolume;

// This represents the volume shipped into each refinery by each type of trucks on each triple
// It is used in defining timing constraints.
dvar int+ inVolumeThroughRefineryOnTruck[triples][TruckTypes] in 0..maxVolume;



constraint maxTruck;
constraint inCapacity;
constraint outCapacity;
constraint flow;
constraint origDest;
constraint timing;

minimize sum(r in routes, t in TruckTypes)
2*r.distance*truckType[t].costPerMile*truckOnRoute[r][t];
subject to {
  // The # of trucks of each type should be less than "maxTrucks", and if a type of truck
  // is impossible for a route, its # should be zero
  maxTruck =
  forall(r in routes, t in TruckTypes)
    truckOnRoute[r][t] <= possibleTruckOnRoute[r][t]*maxTrucks;

  // On each route s-h, the total inbound volume carried by trucks of each type
  // should be less than the total capacity of the trucks of this type.
  inCapacity =
  forall(<s,h,dist> in routes, t in TruckTypes)
    sum(<s,h,dest> in triples) inVolumeThroughRefineryOnTruck[<s,h,dest>][t]
<= truckOnRoute[<s,h,dist>][t]*truckType[t].capacity;
  // On each route s-h, the total outbound volume carried by each truck type should be less
than
  // the total capacity of this type of truck.
  outCapacity =
  forall(<s,h,dist> in routes, t in TruckTypes)
```

```
    sum(<o,h,s> in triples) outVolumeThroughRefineryOnTruck[<o,h,s>][t]
<= truckOnRoute[<s,h,dist>][t]*truckType[t].capacity;

  // On any triple, the total flows in the refinery = the total flows out the refinery
  flow =
  forall (tr in triples)
    sum(t in TruckTypes) inVolumeThroughRefineryOnTruck[tr][t]
    == sum(t in TruckTypes) outVolumeThroughRefineryOnTruck[tr][t];

  // The sum of flows between any origin-destination pair via all refineries is equal to the
shipment between the o-d pair.
  origDest =
  forall (<o,d,v> in shipments )
    sum(t in TruckTypes, <o,h,d> in triples) inVolumeThroughRefineryOnTruck[<o,h,d>][t]
== v;


  // There must be enough volume for a truck before it leaves a refinery.
  // In another words, the shipments for a truck must arrive
  // at the refinery from all depots before the truck leaves.
  // The constraint can be expressed as the following:
  // For each route s-h and leaving truck of type t:
  // Cumulated inbound volume arrived before the loading time of the truck >=
  // Cumulated outbound volume upto the loading time of the truck(including the shipments
being loaded).
  timing = forall (<s,h,dist> in routes, t in TruckTypes)
    sum (<o,h,s> in triples, t1 in TruckTypes, <o,h,dist1> in routes :
        // The expression below defines the indices of the trucks unloaded before truck t starts
loading.
        earliestUnloadingTime[<o,h,dist1>][t1] <= latestLoadingTime[<s,h,dist>][t])
        inVolumeThroughRefineryOnTruck[<o,h,s>][t1] >=
    sum (<o,h,s> in triples, t2 in TruckTypes, <o,h,dist2> in routes :
        // The expression below defines the indices of the trucks left before truck t starts
loading.
        latestLoadingTime[<o,h,dist2>][t2] <= latestLoadingTime[<s,h,dist>][t])
        outVolumeThroughRefineryOnTruck[<o,h,s>][t2];
}
```

2. The Input Parameters Code

```
Location = {A, B, C, D, E, F, G, H, I, J};
TruckTypes = { SmallTruck, BigTruck };

depots = {A, B, C, D, E, F, G, H };
refineries = {I, J};

depot = [<360, 1080>,<400,1150>,<380,1200>,
<340,900>,<420,800>,<370,1070>,<320,700>,<410,1100>];

truckType = [<35,10,55>,<40,15,45>];
loadTime = [[30,55],[35,50]];

routes = {<A,I,20>,<A,J,157>,<B,I,39>,<B,J,118>,
<C,I,20>,<C,J,135>,<D,I,82>,<D,J,217>,<E,I,101>,
<E,J,214>,<F,I,95>,<F,J,80>,<G,I,87>,<G,J,75>,<H,I,70>,<H,J,248>};
shipments =
{<A,B,300>,<A,C,250>,<A,D,350>,<A,E,145>,<A,F,300>,<A,G,125>,<A,H,250>,
<B,A,185>,<B,C,200>,<B,D,221>,<B,E,263>,<B,F,197>,<B,G,220>,<B,H,180>,
<C,A,143>,<C,B,178>,<C,D,258>,<C,E,221>,<C,F,106>,<C,G,190>,<C,H,110>,
<D,A,75>,<D,B,135>,<D,C,245>,<D,E,283>,<D,F,155>,<D,G,260>,<D,H,165>,
<E,A,123>,<E,B,234>,<E,C,143>,<E,D,78>,<E,F,107>,<E,G,98>,<E,H,115>,
<F,A,201>,<F,B,157>,<F,C,169>,<F,D,212>,<F,E,104>,<F,G,201>,<F,H,99>,
<G,A,215>,<G,B,147>,<G,C,149>,<G,D,190>,<G,E,114>,<G,F,210>,<G,H,199>,
<H,A,181>,<H,B,137>,<H,C,139>,<H,D,180>,<H,E,124>,<H,F,160>,<H,G,221>};
```