IMPROVING THE PRODUCTIVITY OF MARINE CONTAINER TERMINALS

by

Jyotirmaya Behera

A thesis submitted in fulfillment of the requirements for the degree of Master of Engineering

School of the Built Environment
Victoria University of Technology
Melbourne, Australia

February 2000

DECLARATION OF CANDIDATE

This thesis contains no material that has been accepted at another university for the award of a degree, and to the best of the writer's knowledge and belief, the thesis contains no material previously published by others, except where specific reference is made.

(Jyotirmaya Behera)
Melbourne
February, 2000

SUMMARY

The research presented in this thesis is concerned with several facets of the management of container terminals.

One facet of the research was to test the hypothesis that it is difficult to compare the productivities of container terminals. This is because the measures used to calculate productivity vary from operator to operator. In this work variability of productivity measures has been studied by analysing the time deductions that are applied to the operation of vessels and quay cranes when their productivity is being calculated. This initial study was carried out at West Swanson Dock, a container terminal located in Melbourne, Australia. It provided a corpus of knowledge that enabled the formulation of a survey questionnaire to investigate the performance measures of a number of container terminals in Australia and Asia. Results of the survey confirmed the hypothesis that productivity measures in container terminals are indeed highly variable from operator to operator.

Managers require sensitive tools to allocate resources within container terminals. At any moment of time the activities within a container terminal are the result of many interacting stochastic events. Management tools that are based on deterministic formulation are intractable, hence in this research a simulation approach has been adopted. The results of the simulations have been generalised by making use of response surfaces that indicate the interactions between operating variables that may be influenced by managers. The raw data used to develop the simulation models were gathered by the candidate during the course of the work reported in this thesis. These data were then fitted to appropriate probability distributions.

The resulting simulation model was used to explore how resources such as the number of entry gates to a terminal, the speed at which documentation is processed, the distribution of parking space for trucks in the terminal and so on affect productivity. An outcome of the research has been to demonstrate that the throughput of the terminal can be increased from typically 880 trucks per day to 1150 trucks per day by halving the processing times of the trucks at truck parking spaces and by allowing the arrival rate to be increased by

50%. The resource allocation employed at present in the West Swanson Dock is such that it is operating very close to its maximum capacity.

The simulation model developed as part of this research was used also to investigate the deployment and characteristics of the straddle carriers (mobile cranes) on the performance of the terminal. It was found that an increase in the number of straddle carriers resulted in no increase in throughput of the terminal in the present set-up. But an increase of straddles to 7 is expected to have a profound effect on reducing the average waiting time of trucks from 16.58 minutes to 8.86 minutes, a decrease of 46.5%. At present drivers operate the straddle carriers at relatively low speeds, whereas an increase in average speed to 20 km/hour would result in throughput of the terminal increasing by about 5% in the present set-up. As part of this work a proposed heuristic job assignment rule for straddle carriers has been tested. The results indicate that both heuristic rules (present and proposed) performed equally well on average container flow time, daily throughput, average waiting time of jobs, number of jobs in the queue for service by straddles, and straddle utilisation. Therefore, the proposed heuristic job assignment rule cannot be considered for implementation.

Information technology is becoming all pervasive and it is changing the very nature of business operations. In this work the penetration of information technology in container terminals in Australia and Asia has been investigated by means of a questionnaire sent to terminal–operators. The analysis indicates that the application of information systems and information technology is limited to larger capacity terminals and there is considerable scope for the implementation of more sophisticated management information systems in smaller terminals. More than 80% of container terminals in Australia reported that benefits from standardisation of container location in yards lead to higher productivity.

The facets of research into the management of container terminals reported in this thesis done little more than highlight the need for an integrated research program. The research has revealed a veritable cornucopia of research opportunities, some of which are discussed in the thesis.

ACKNOWLEDGEMENTS

There are many people that I need to thank, who assisted and supported me throughout the entire period of my research. There were many obstacles and hurdles that I faced along the way, and without the people close to me, this thesis would not have been possible to complete.

Firstly, I wish to express my sincere gratitude to my thesis supervisor Associate Professor Graham Thorpe for the enthusiasm he has shown towards this thesis and for his highly attentive level of advice and guidance. My dream of completing this thesis would never become true without his scrutiny of so many revised versions of the thesis.

I would like to express my thanks to thesis co-supervisor Associate Professor Chandra Bhuta for his constant help and advice during this research. He gave me many suggestions during the entire period of my research especially during the survey of container terminals. I am also in his debt for reading the final draft of the thesis.

I would also like to express my sincere thanks to thesis co-supervisor Dr Neil Diamond (School of Communications and Informatics) for his invaluable encouragement and guidance during the simulation phase of this research. Without his help, it would not be possible to complete my simulation especially using of response surface methodology. I am also in his debt for his reading chapters 1, 3, 4 and 5.

I am also thankful to Mr Alan Davidson, Senior Lecturer, School of Communications and Informatics, VUT for providing SIMAN IV, and ARENA 3.0 simulation software during the initial stage of my research. I am also thankful to Associate Professor Michael Sek, Head of the School of the Built Environment and Associate Professor Graham Thorpe for procuring the ARENA 3.5 simulation software for my work.

I am indebted to Mr Ron Beattie, the former Manager, Container Handling Victoria, P&O Ports Limited for his enthusiastic support of this research and grant of permission to use West Swanson Dock facilities, Melbourne. Without his permission, this research could not have been carried out. Particular thanks are due to Mr Chris Vicary, Operations Manager, West Swanson Dock for providing their office accommodation, computing services, and access to their data. I would like to take this opportunity to thank Mr Michael Povazan, Business Analyst, West Swanson Dock for his friendly supervision, facilitating the work, and provided background on the container terminal operation. I wish to express my appreciation to all staff at West Swanson Dock, Melbourne who provided a great deal of assistance and unfailing discussions whenever I approached to them for my research.

I wish to express my appreciation to Alison Sambell, Market and Trade Analysis, Melbourne Port Corporation for providing information on traffic through West Swanson Dock and information on container trade through Melbourne Port.

My friends in the school, in particular Abdullah Ozer, Annie Yang, Fashiur Rahman, Gino Catania, Hani Nahlawi, Mahesh Prakash, and Sujay Karkhanis who have in one way or another, rendered their kind assistance. Friends - many thanks. I could not have completed these studies without your support.

Special thanks to Ms Angela Rojter, Student-Learning Unit of the University for the English language corrections she suggested to this thesis. I would like to thank Ms Glenda Geyer, Senior Secretary, School of the Built Environment for her help in all administrative matters.

I wish to express my thanks to Government of India for financial support in the form of National Overseas Scholarship.

I would like to thank those container terminals in Australia and Asia for responding to the questionnaire on current practices of performance indicators and information management systems.

Finally and most importantly, I would like to express my sincerest gratitude to my mother, father, my sister and younger brother for their continuous support, patience and encouragement. To them I dedicate this thesis.

Jyotirmaya Behera
February, 2000

CONTENTS

PUBLICATIONS ARISING FROM THIS WORK

- Behera, J. M., Bhuta, C. J., and Thorpe, G. R. (1999), "Management Information Systems: An Overview of Present Practices at Marine Container Terminals", Internal Research Report, ISBN 1862725438, School of the Built Environment, Victoria University of Technology, Footscray Park Campus, Melbourne.

- Behera, J. M., Bhuta, C. J., and Thorpe, G. R. (2000a), "State of the Practice of Performance Related Delays at Marine Container Terminals", *In Proceedings of 'Sea Australia 2000': Australian Maritime Conference*, 1-3rd February, Sydney.

- Behera, J. M., Diamond, N. T., Bhuta, C. J., and Thorpe, G. R. (2000b), "Simulation: A Decision Support Tool for Improving the Efficiency of the Operation of Road Vehicles in Container Terminals", *In Proceedings of the 9th ASIM Dedicated Conference on Simulation in Production and Logistics*, 8-9th March, Berlin, Germany, pp. 75-86.

- Behera, J. M., Bhuta, C. J., and Thorpe, G. R. (2000c), "Management Information Systems: An Overview of Present Practices at Marine Container Terminals", Accepted for publication in the *Journal of Transportation Quarterly* (Print will either the Summer or Fall 2000 issue, depending on scheduling).

- Behera, J. M., Diamond, N. T., Bhuta, C. J., and Thorpe, G. R. (2000d), "The impact of job assignment rules on throughput for straddle carriers on throughput of container terminals", Accepted for publication in the *Journal of Advanced Transportation* in Volume 34-3 (2000).

- Behera, J. M., Diamond, N. T., Bhuta, C. J., and Thorpe, G. R. (2000e), "Using metamodels in simulation experiments to examine straddle carrier performance in container terminals", To be published in *Proceedings of the International Conference on Harbour, Maritime & Multimodal Logistics Modelling and Simulation*, SCS Int., 5-7th Oct 2000, Portofino, Italy.

GLOSSARY OF ACRONYMS

AEI	Automatic Equipment Identification
AGV	Automated Guided Vehicle
BIE	Bureau of Industry Economics
BTCE	Bureau of Transport and Communications Economics
BTE	Bureau of Transport Economics
CCTV	Closed Circuit Television
CITOS	Computer Integrated Terminal Operations System
CNRS	Container Recognition System
DLR	Discharge, Land and Restow
EDI	Electronic Data Interchange
EIR	Equipment Interchange Receipt
ERA	Export Receival Advice
ETD	Earliest Time of Departure
FIFO	FirstIn-FirstOut
GPS	Global Positioning System
IT	Information Technology
MDT	Mobile Data Terminal
MDU	Mobile Data Unit
P&O	Peninsular and Oriental
PC	Productivity Commission
PDI	Port Development International
PDS	Position determination System
POR	Preferred Order Rule
RD	Road Delivery
RDT	Radio Data Terminal
RO RO	Roll On Roll Off
RR	Road Receival
SDS	Smallest Distance from Station
SOB	Shift on Board
SPARCS	Synchronous Planning and Real Time Control System
TCS	Thomson Clarke Shipping
TEUs	Twenty-foot Equivalent Units
TTR	Truck Transaction Reference
UNCTAD	United Nations Conference on Trade and Development
VBS	Vehicle Booking System

DEFINITIONS

DSTATS	Statistics collection variable in ARENA
NE	Number of entities transferring
NQ	Number in queue
NR	Number of busy resource units
NT	Number of busy transporter units
TNOW	Current simulation time

NOMENCLATURE

a	minimum parameter value
a_{φ}	acceleration of straddle carrier
b	maximum parameter value
C_j	cumulative probability
C_{jj}	diagonal element
D	calculated K-S statistic
d	degree of polynomial
F_c	cumulative distribution
f_e	expected frequency
f_i	relative frequency of the data for the ith interval
f_j	observed frequency in the jth interval
F_0	comparison of two variances
$G^*(x_i)$	theoretical cumulative distribution
h	half width of the confidence interval
h^*	desired half width of the confidence interval
H_1	alternative hypothesis
H_0	null hypothesis
k	number of intervals
l	number of observations
m	mode parameter
n	number of data points
n^*_r	total number of replications required
N	degrees of freedom
n_r	number of replications in a pilot run
n_f	number of points used in the factorial portion of the design
p	probability
P_j	expected proportion of the frequency that will fall in the jth interval
P_p	number of population parameter
q	number of columns in a matrix
r	number of experimental factors

s	sample standard deviation
t	independent Bernoulli trials
t_0	test statistic
t_φ	time required by the straddle carrier to reach the final velocity
u	number of input variables
x_u	coded variable
X	matrix of independent variables
X'	transpose of matrix
X_u	input (natural) variable
$\bar{x}$	sample mean
X_R	sample observation recorded on the Rth replication
Y	vector of observations
y_i	observed value of the ith observation
y	response variable
$\hat{y}$	predicted response

GREEK SYMBOLS

α	shape parameter
α_n	significance level
α_r	distance of star points from the design centre
β	scale parameter
χ^2	calculated Chi-square statistic
χ_φ	straddle carrier position at any time t_φ
$\chi_{\varphi 0}$	straddle carrier position at $t_\varphi = 0$
δ	input variable
ε	random error
γ	location parameter
Γ	gamma function
η	mean response
λ	mean
μ	mean
ν	degrees of freedom
ν_φ	maximum velocity of straddle carrier at time t_φ
$\nu_{\varphi 0}$	the velocity of straddle carrier at time $t_\varphi = 0$
σ	standard deviation
ω	regression coefficient
ψ	input variable

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1. Introductory review

Over 90% of world trade is carried out through sea ports and 80% of seaborne cargo is transported in containers. In Australia container terminals play an important role in the economy. In terms of volume, approximately 99% of imports and 96% of exports were transported by sea during 1995/96 period. In terms of value, 70% of imports and 78% of exports were transported by sea. About 66% of the value of sea imports and 40% of the sea exports were in containers in the same period (Productivity Commission (PC), 1998a). Approximately 98% of imports and 80% of exports enter through the major container terminals located in Sydney, Melbourne, Adelaide and Fremantle. Of these, 75% of imports enter through either Melbourne or Sydney. The Melbourne container port currently handles 38% of the Australia's container trade, which is the highest of any container port in Australia. Container trade in Melbourne is well ahead that of Sydney and almost double the volume of Brisbane, Fremantle and Adelaide combined (Trade & Transport Review, 1997/98). Over the past five years trade has grown by more than 50% in Melbourne which has led to significant growth in container traffic due to high demands from importers and exporters (Trade & Transport Review, 1996/97). For example, container traffic through a major container terminal such as Swanson Dock West constituted 43% of the total throughput through Melbourne Port in 1997/98 and 41% in 1998/99. Managers of container terminals are faced not only with rapid growth in their businesses but they are also under pressure to maintain an efficient service to their clients such as trucking and shipping companies. Such pressures invite their consideration of sharper management tools such as simulation and a greater use of information technology. One influential newspaper in Australia has reflected a widely held view that container terminals are overmanned, strike-prone, unreliable, expensive and slow working compared with best overseas ports (Colebatch, 1997 and 1998).

Moving containers to and from the vessel through storage yards and gates involves the services of a number of agents. They include the container terminal operator, shipping lines, customs brokers, port authorities, cargo insurers, quarantine, trucking companies, freight forwarders, importers, exporters, trading banks, rail freight offices, shipping agencies and container depots. The ranges of activities for which they are responsible include loading, unloading, delivery, collection, clearance, and preparation of documentation for all types of containers. A problem encountered by any of these agencies can easily have an adverse effect on all of the other agencies. Efficient sea-land interface operations depend on the containers terminal operator undertaking their activities in a timely and reliable fashion.

The problems associated with inefficiencies and congestion in container terminal facilities have been addressed by a number of Australian Government sponsored agencies including the Bureau of Industry Economics and Productivity Commission. The main factors influencing terminal operations are their operating strategies, physical layout, work practices, handling equipment, vessels' plans, berth layout, and management information systems. Substantial work has been reported in the performance of container terminals. However published research findings are generally inadequately detailed to enable significant conclusions to be drawn, particularly measures of operating efficiency, methods of calculating delays that occur in container terminals, and the actual reasons for delays at berths to vessels. These elements provide one thread of the research reported in this thesis.

The complexity of the analysis of the operation of container terminals results from the variety of stochastic processes at the sea-land interface and landside operations of terminals. The analysis of such complex stochastic processes is practically impossible by deterministic mathematical models; computer simulation is a frequently used method of analysis. The use of simulation of terminal operations is shown to be beneficial in terms of identifying bottlenecks and searching for alternative strategies to improve their efficiency. A review of the current literature has indicated that the applications of simulation in container terminal differ widely in their objectives, detail and the factors they take into consideration. This thesis presents in detail the methodology and empirical observations used in formulating a simulation model of a container terminal. Whilst the primary objective of this component of the research is to investigate how the performance of the terminal might be improved, a secondary aim is to present the work in detail and with a high degree of transparency. Finally, a survey is conducted to establish the implementation of management information systems in the context of Australian and Asian terminals.

1.2. Aims of the research

The research reported in this thesis aims to establish several aspects of the management of container terminals within a sound intellectual and quantitative framework. There are four distinct, but related facets of the research. These are:

- To examine how delays in the operation of container terminals are measured and reported. This is important because terminals use their own individual methods of reporting productivity. For example, some terminal operators may measure the total time that a quay crane operates but they deduct the times of meal breaks, say. Other terminals may not deduct such times. The former terminal would have an apparently higher productivity.

- To develop discrete event simulation models of the movements of the road vehicles as they enter the terminal, and how loaded or unloaded containers are handled within the terminal. The ultimate objective of this research is to explore strategies that will reduce the time that road vehicles spend within the terminal and improve the throughput of road vehicles. A feature of this research is that the results have been generalised by using polynomial response surface approximations called response surface methods to model the relationship between the inputs and outputs of the system.

- To develop discrete event simulation models in order to investigate how to best use straddle carriers (mobile cranes) in an existing layout of a container terminal, and with current operation parameters in the layout including number of straddles needed, straddle speed, road vehicles arrival distribution on grids, and heuristic rules for straddle selection. A more theoretically driven aim is to suggest better operating conditions based on central composite design experiments on the simulation model. The central composite design allows the fitting of a second-order model which serves as an adequate approximation to the true relationship between the inputs and outputs of the system.

- To establish the kinds of information system deployed in container terminals in Australia and Asia.

1.3. Significance of the project

Performance indicators used by individual container terminals need to be treated with caution if they are to be used to make comparisons with other container terminals because there are no standard methods of categorising the events that cause delays to the vessel and quay cranes. This thesis presents an attempt to find out the reasons for delays to vessels and quay cranes, and to identify how other terminals in Australia and Asia treat differently various delays used to measure the vessel and the quay crane productivity.

Container terminals will not be able to run effectively unless management is able to co-ordinate the ability to transfer containers quickly from vessels, through storage yard areas to gates, and vice versa. In a landside (terminal and road interface) operation any lack of co-ordination between the terminal operator and the trucking companies can often result in truck queues at the terminal gate. The resulting long queues at gates can have direct impact on exporter and importer operations and reflects inadequate levels of service for receival and delivery of containers. The delays associated with truck queues at gates and the inefficient use of transport resources increase the cost of container handling to both exporter and importer. In this regard trucking companies are expecting a shorter turnaround time within a container terminal irrespective of any operational problems. The levels of service provided in terminals can be accurately explored by making use of simulation.

The level of services to trucking companies within the terminal depends upon the availability of handling equipment such as straddle carriers. Straddle carriers also serve quay cranes in seaside operations for loading and unloading of vessels. The movement of straddle carriers within the terminal necessitates reduced handling times in order to achieve shorter turnaround time of trucks, because the maximum waiting times trucks in a terminal is spent in waiting for service by straddle carriers. When a truck is waiting to be served, the requirement of straddle carrier is time-phased. As the number of trucks in the terminal increases, the problem ultimately becomes intractable. When more straddle carrier operate in the terminal, the control of the system is not an easy task because of various concerns such as number of straddle carriers required, traffic control, and straddle selection all have to be considered simultaneously. The significance of this research is to identify a suitable control of straddles and how delays are to be minimised at existing facilities so as to find a way to increase the overall throughput.

There is a great pressure on all container terminals to improve the services provided to trucking companies and shipping lines and *ipso facto* there are increasing requirements for all forms of electronic communication with entities such as customs, brokers, banks, and regulating authorities. In this regard, the support of effective management information systems is essential to be able to satisfy these demands. As part of developing strategies at the national and individual enterprise levels it is important to assess the level of implementation of information technology and information systems. As a result it may be possible to develop highly efficient and integrated management systems. The results of this research suggest that systems are unevenly implemented and various practices are currently in use at container terminals.

1.4. Outline of the thesis

The thesis is divided into seven chapters and nine appendices.

Chapter 1: Introduction. An introductory review relating to the research together with the aim of the research and significance of the research.

Chapter 2: Criteria for measuring the performance efficiency of container terminals. The operating efficiency of a container terminal is discussed as a case study. The actual reasons of delays at berths to the vessels are also described, including a comparison of performance-related delay practices between Australian and Asian container terminals.

Chapter 3: A simulation approach to the operation of container terminals. The method of terminating simulation in this study is discussed. The response surface method is used to plan each experiment to support an appropriate regression model. A central composite design consisting of cube runs, axial runs, and centre runs for formulating the simulation experiments is also discussed.

Chapter 4: Simulation modelling of the movement of road vehicles in terminals. The modelling of road vehicles entering and exiting the terminal is presented. Different scenarios with changing resources suggested by the management are addressed. The study of functional relationships between the average turnaround time, average total trucks, average parking grid utilisation and the variables such as percentage increase in arrival of trucks and percentage decrease in processing time are described by using response surface methodology.

Chapter 5: Simulation modelling of straddle carrier operations between the truck grid and the yard area of terminal. Evaluation of the performance measures with multiple straddle carriers is presented. Various parameters such as the number of straddles needed, straddle speeds, heuristic rules for straddle selections, and arrival of trucks distribution are tested. The comparison of performance of proposed heuristics job assignment rule of straddles with present job assignment rules is presented. A central composite design simulation experiment is discussed for reducing the simulation time.

Chapter 6: Present practices of management information systems at marine container terminals. This chapter presents a comparison of the present practice of management information systems between Australia and Asian container terminals.

Chapter 7: Conclusion and recommendations for further research.

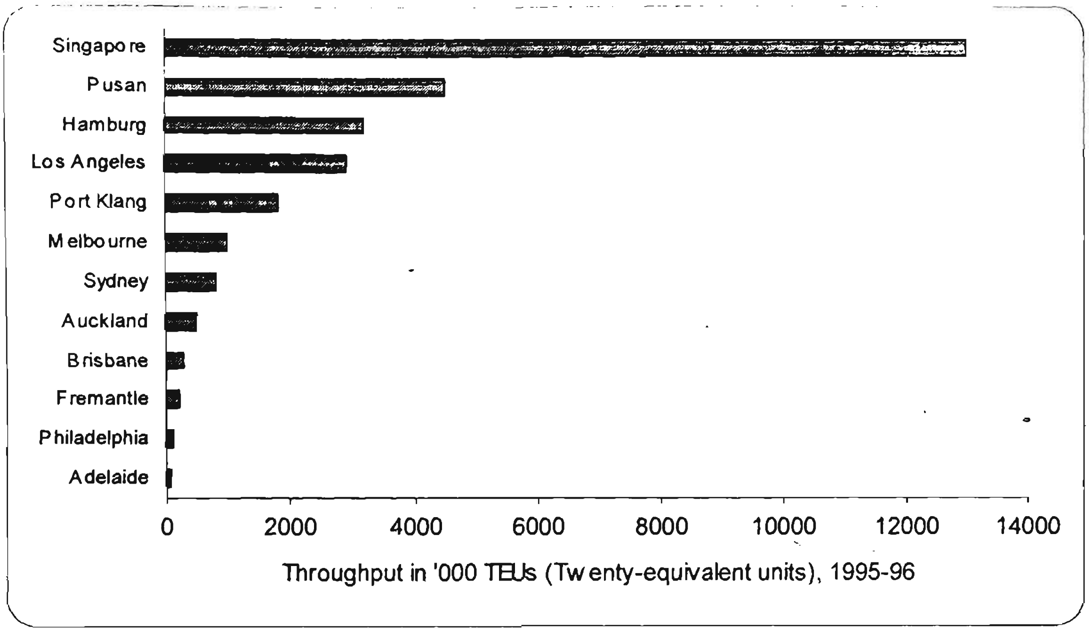
CHAPTER 2

CRITERIA FOR MEASURING THE PERFORMANCE EFFICIENCY OF CONTAINER TERMINALS

2.1. Introduction

A marine container terminal is the interface between sea and land transport within the port. The nature of container service operations varies according to the type of container, the nature of the vessel, and the characteristics of the container terminal. The container terminal is usually seen as an interdependent chain of services and, from a user's perspective, its performance is affected by the performance of the services provided by the management. Container terminal management needs to know whether the service they are giving to their customers, and the way in which they are utilising their facilities to provide it, is improving or deteriorating. This chapter reports research carried out by the candidate aimed at establishing rational bases for performance criteria at container terminals.

Marine container terminals throughout the world maintain different levels of container handling productivities. The productivity levels determine the container throughput an individual container terminal achieve. However, apparent throughputs around the world vary due to different container handling performance measures (Vandeveer, 1998). In Australia it is quite common to hear the excuse "it is the container terminal – you know" for any delay regardless of where in the chain it happened (Berg, 1998). Container terminals are still the largest single bottleneck in the distribution chain. In container terminals where capacity does not keep pace with demand, bottlenecks arise which have been the subject of national debate in Australia when discussing congestion. In 1997-1998 one of the leading newspapers in Australia reported slow working compared with the best overseas ports (Colebatch, 1998). The Productivity Commissioner of Australia in his report said the handling rates (lifts per net crane hour) at Australian container terminals were generally below those at overseas ports for the same vessels. Throughput at Australian container terminals is small as compared with major terminals in Asia, North America, and Europe (PC, 1998b) (see Figure 2.1).



Source: TCS (1997)

Figure 2.1. Statistical comparison of throughput of Australia's container ports (Melbourne, Sydney, Brisbane, Fremantle, and Adelaide) with selected overseas container ports.

The first productivity study is attributed to Melessen (1969). This study established yardsticks to evaluate productivity in traditional break bulk stevedoring and highlighted the man-hour performance of the direct workers aboard the vessels. Suykens (1983) has studied cargo-handling productivity in European seaports. This study is based on general cargo handling. Robinson and Reyes (1984) have conducted a study on efficiency and productivity in the context of South East Asian Ports and Australian Ports. They focussed on throughput and productivity in the early 1980's for conventional cargo handling as well as container handling. Ashar (1985) suggests using vessel operation reports for analysis and developing a common way of assessing the operational data. The author also urged measures be selected that are considered meaningful according to terminal management goals. Monie (1987), under the project by United Nations Conference on Trade and Development (UNCTAD) for port management, has attempted to analyse factors that determine the performance of ports and suggested methods of measuring port indicators. However, their report calls for an in-depth investigation of a terminal's structure and the information about its different system components and control units. The vessel and quay crane performance measures have imperfect reporting formats. The main reason for this is that there are no standard methods of categorising the events which cause delays to vessels and quay cranes. As a result, the current reporting format makes it difficult for direct comparisons between the productivities of container terminals (McGovern, 1988). McGovern maintains that a record of deductions and a suitable analysis of recorded data should allow for a simplistic identification of problem areas. He also suggested extending data collection and analysis for containers. In their report the Bureau of Industry Economics in Canberra, Australia, note that container crane productivity at Australian terminals in terms of twenty-foot equivalent units (TEUs) per crane per hour, was less than half that of major Asian ports and markedly less than major ports in Europe and North America (BIE, 1993). Again another Australian government organisation, the Bureau of Transport and Communications Economics, in their report also made observations similar to those of BIE on Australian container terminals (BTCE, 1995).

Ward (1998) concludes that many terminals experience productivity losses due to non-container related handling delays. Many of the quay operation delays are caused by mechanical failures, inter-connectors, lashings, removing vessels' hatch covers, non-container freight, oversize or over weight freight, and variations in labour performance are unavoidable and need to be accounted for in reporting the crane operation. Vandeveer (1998) reports that standardized productivity measures should be used to benchmark containerized cargo operations. These include throughput per terminal area, utilization rates of key equipments, berth utilisation, and vessel loading/unloading rates. Walker and Helmick (1998) note that container ports frequently focus on internal and narrowly construed measures of productivity and efficiency. For example, the number of containers moved across the berth each hour is often the focus of marine terminal operators but it is not a measure that is generally of great concern to users of the terminal. For shipping lines, the degree to which the terminal facilitates efficient container operation is normally of far greater importance. Each measure offers a unique perspective into productivity standards. However, container terminal experiences indicate that the reporting format of each of these measures is imperfect to a significant extent.

Most of the previous work does not describe the actual reasons for delays to the vessels whilst they are at berth. Furthermore, there are no standard methods of categorising the events that cause delays to container vessels whilst they are at berth. As a result it is difficult to make comparisons between the productivity of container terminals. Deductions from gross working time are made in an arbitrary manner with regards to both vessels and quay cranes. For example, the deduction factors used to estimate the handling rates (number of containers per net crane hour) in one container terminal is not the same as in other container terminals because most terminal operators have arbitrary time deduction factors. Each terminal appears to have a unique method of estimating the net working time of vessels or quay cranes. The absence of a commonly agreed performance related criterion for delays among operators leads to the reporting of unreliable and inaccurate data. In any case, delay factors always govern the operational efficiency of container terminals. Terminal operators make deductions from gross working time in an arbitrary manner with regards to both vessels and cranes.

This chapter seeks to achieve two objectives. The first is to measure the operating efficiency of a container terminal. This addresses what are the actual reasons of delays at berths to the vessels. This analysis of delays was used as a framework to analyse the present practice of performance-related delays. The second objective is to compare the performance related delays of Australia's container terminals against that of Asian container terminals.

2.2. Methods adopted

A case study has been carried out with the aim of identifying the constraints affecting the productivity of container terminals. The actual observational study is based on analysing quantitatively the real life situation in container terminals. An analysis was made of the performance of vessels and quay cranes with regards to delays as part of this container terminal productivity study. The management of a container terminal located in Melbourne, Australia, has permitted this approach. An analysis, over a period of three months, from 1st Sept 97 to 2nd Dec 97, was made of the manner in which the vessels of 13 shipping lines were handled (see Table 2.1).

Table 2.1. Shipping lines entering or leaving the container terminal on a regular basis for the period over three months (i.e. 1st Sept 97 to 2nd Dec 97).

Serial No.	Trade (Shipping lines)	Serial No.	Trade (Shipping lines)
1	ANRO	8	MISC
2	ASA	9	MKKBRD
3	COSCO	10	OOCL
4	FANAL	11	POZ
5	FESCO	12	SCANS
6	JECEUR	13	TASMAN
7	JECMED		

Over 150 vessels' container handling operations were studied. The terminal has a higher proportion of demand for container services during the above months, when wholesalers and retailers stock up for the Christmas season. A total of 95,550 containers (123,342 TEUs) including DLR (Discharge, Land, and Restow) and SOB (Shift on Board) are involved, which is no doubt a representative sample as shown in Table 2.2. The variation in container handling is illustrated by Figures 2.2 and 2.3, which shows a larger share of import than export containers.

A survey questionnaire was sent to Australian and Asian operators of container terminals for the study of a second objective, namely to understand the generic practices of deduction factors for estimation of performance measures (see Appendix I).

Table 2.2. Container handling for the period 1st Sept to 2nd Dec 1997.

Container type	Import containers	Export containers	DLR containers	SOB containers
20 ft	37,818	28,769	1,116	55
40 ft	14,514	12,703	552	23
Total	52,332	41,472	1,668	78

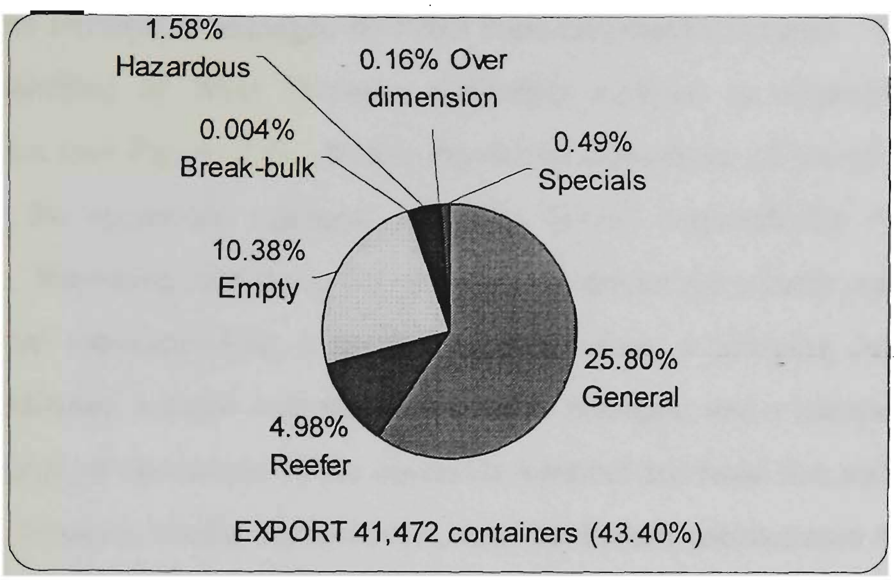


Figure 2.2. Percentage distribution of export containers exchanged.

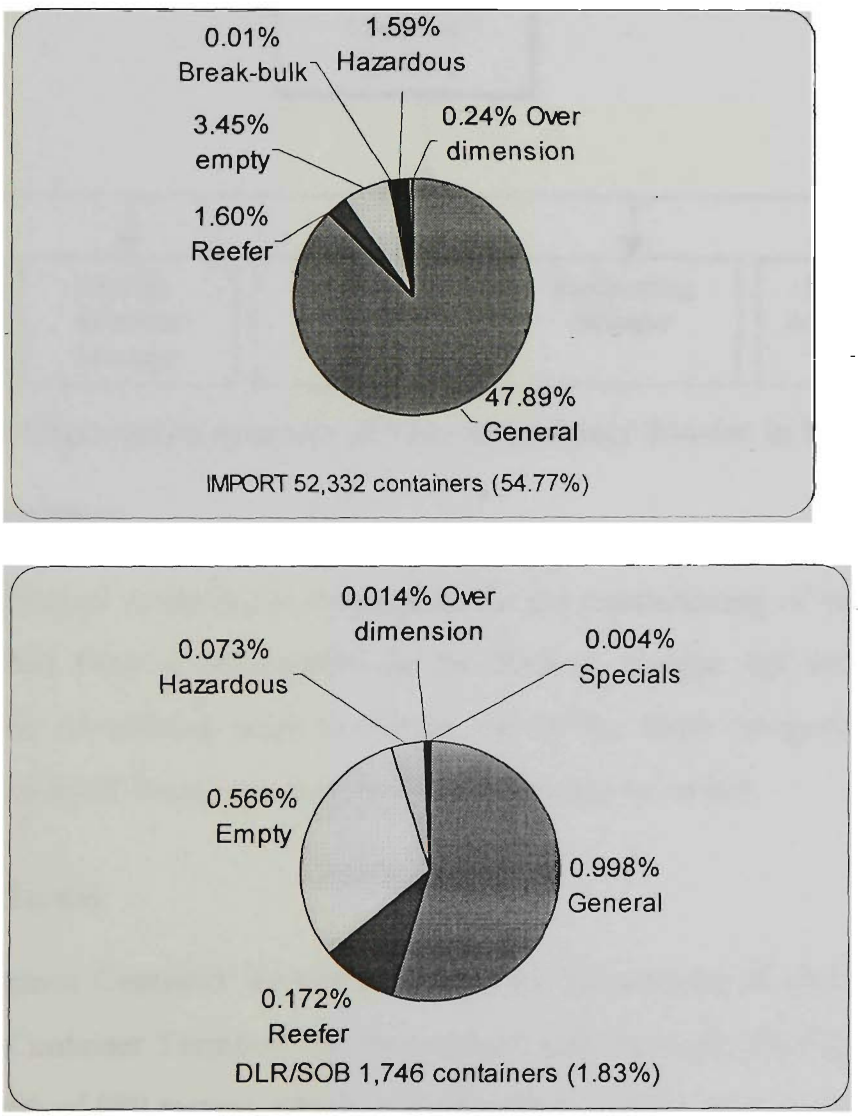


Figure 2.3. Percentage distribution of import and DLR/SOB containers.

2.3. The Management system

The container terminal is managed by P&O Ports (Australia) Limited. The manager, container handling of West Swanson Container terminal is responsible for the administration (see Figure 2.4). In the day-to-day operations of the terminal, he is assisted by the operations manager, who has overall responsibility for container movements. Reporting directly to the operations manager are a berth superintendent, an operational superintendent, a project superintendent, a planning superintend, a labour co-ordinator, a cargo care person, a RORO manager, and a transport manager. In direct charge of operations of the container terminal are front line staff, including supervisors, foremen, clerks, crane drivers, straddle drivers, maintenance staff, general clerks, reefer staff, watchmen, support service providers and casual drivers.

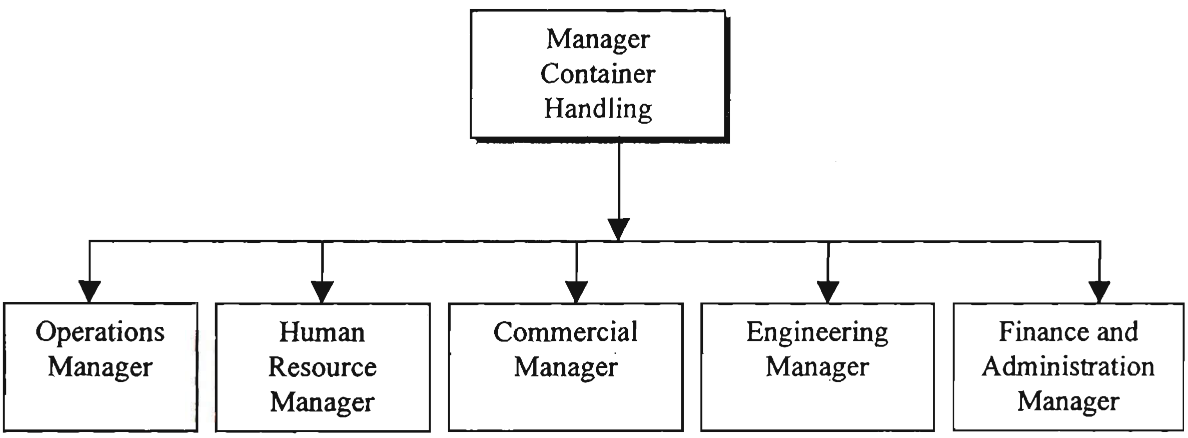


Figure 2.4. Organisation structure of Victoria container division in Melbourne.

2.3.1. Responsibilities

The Victoria Channel Authority is responsible for the manouvering of vessels to the berth area. P&O Ports is responsible for the landing, storage and delivery of all containers. The stevedoring work is carried out by the same company, who also carries out shipment of containers and provides assistance to vessels.

2.4. Terminal layout

The West Swanson Container Terminal, located on 26 hectares of land adjacent to East Swanson Container Terminal, can be accessed only by road (see Figure 2.5). It has a quay length of 980 meters, which comprises four berths – two on the north side i.e. for the North Park and another, two on the south side i.e. for the South Park of terminal.

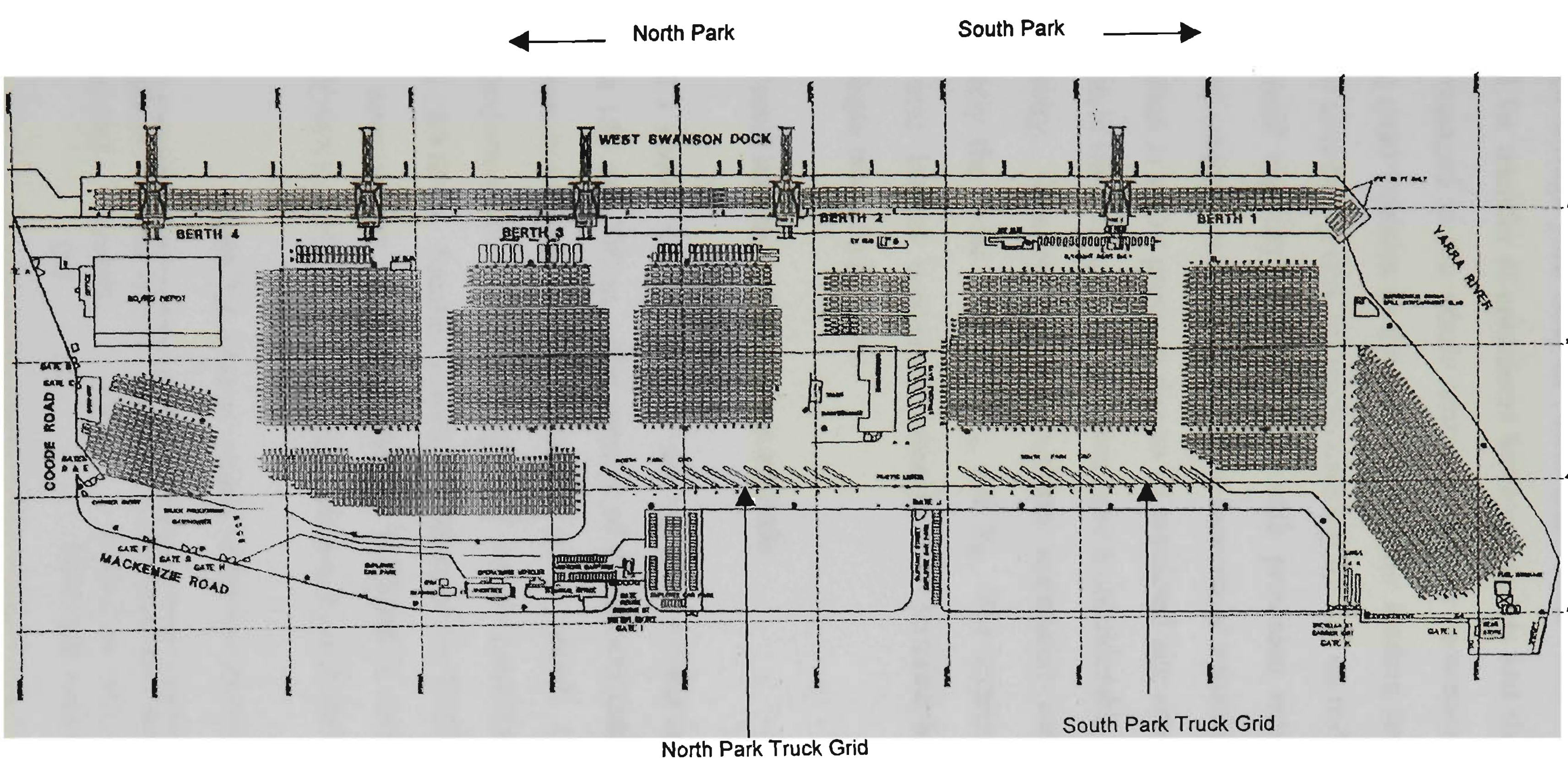


Figure 2.5. Layout plan of a West Swanson Dock located in Melbourne.

This terminal is operated by straddle carriers for container movements with the two-stack high storage yard both in North and South Parks. There are six quay cranes deployed for transfer of containers between vessels and shore. There are 30 straddle carriers engaged in the whole terminal area for movement of containers as well as servicing road vehicles in the parking grid for loading and unloading of containers. There are four heavy fork lift trucks catering for roll on roll off (RO RO) vessels. The total ground capacity is 6200 TEUs with provision existing for 500 TEUs reefer containers (stacked two high). With the theoretical volume of 565,000 TEUs per year, the terminal is under pressure due to its restricted site area, problems of storage, and road vehicle movements which in turn have a considerable impact on vessel and crane productivity. The operational problems associated with quay cranes are severe particularly the older cranes P_1, P_5, and P_6. The terminal has no specific area for export and import containers because the terminal-handling system does not discriminate between the two.

2.4.1. Vessel length and container arrivals

Table 2.3 shows that 49.33% of the vessels arriving at the terminal had lengths between 150 and 200 m. The number of containers exchanged between vessel and shore does not depend solely on the size of the vessel. Using the observations from vessel performance reports, the lengths of vessels could be as small as 118.00 m or as large as 289.60 m. Smaller vessels are operated by TASMAN and larger vessels are largely operated by ANRO, JECMED, MKKBRD, OOCL, and SCANS shipping lines. COSCO and SCANS shipping trade mostly operate RO RO vessels.

Table 2.3. Size of vessels using the container terminal.

Length of vessel (m)	No. of vessels, (n)	% of total	Containers exchanged (Min data value – Max data value)	Containers exchanged (Min data value - Max data value) in TEUs
$118 < n \leq 150$	23	15.33%	180 - 717	211 - 717
$150 < n \leq 200$	74	49.33%	157 - 1385	204 - 1798
$200 < n \leq 250$	33	22.00%	374 - 1354	429 - 1847
$250 < n \leq 290$	20	13.33%	19 - 1372	29 - 1831
Total	150			

Table 2.4 shows that about 55% of vessels exchanged between 501 to 1000 containers. The terminal is handling about 637 containers (average). or 822 TEUs (average) per vessel.

Table 2.4. Container exchanged for a period from 1st Sept 97 to 2nd Dec 97.

Containers exchanged	No. of vessel	Percentage of total vessel
Upto 500	53	35.3%
501 to 1000	82	54.7%
1001 to 1500	15	10.0%
Total	150	

2.5. Performance measures for container handling on vessels and on quay cranes

Total turn-around time of vessels arriving at or leaving the container terminal has been examined over a period of three months and the data are presented in Table 2.5. The table shows that 72% of container vessels have spent between one to two days in the port. It is essential that we analyse the times to complete a range of activities whilst vessels are at berth.

Table 2.5. Vessel turn-around time in port.

Turn-around time of vessel during the call to the container terminal in hours	No. of vessels	Percentage of vessels
0 to 24	18	12.00%
25 to 48	108	72.00%
49 to 72	22	14.66%
73 to 96	1	0.67%
97 to 120	1	0.67%
Total	150	100.00%

Productivity measures determine whether the container terminal is too congested to receive waiting vessels. In container terminals the most commonly used indicators for the exchange of containers are vessel time in port, elapsed berth time, elapsed labour time, gross working time, gross crane time, net crane time, containers per net crane hour, and crane intensity as shown in Figures 2.9 and 2.10. A reduction of any of these times may improve the overall productivity of the container terminal. These indicators are discussed in more detail in the following sections.

2.5.1. Vessel stays at terminal

The average vessel turn-around time in port is about 38.1 hours. Vessels are experiencing a pre-berthing waiting time of about 1.8 hours and post-berthing waiting time (sailing delay) of 1.0 hours. The reason for the higher pre-berthing waiting time could be the need to wait before berthing because berths are already occupied and manoeuvring time of vessel from port limit to berth. The average elapsed vessel time or elapsed berth time (see Table 2.6) for over three months shows that 72% vessels exceed one day and about 13% of vessels exceed more than two days.

Table 2.6. Elapsed vessel times for the container terminal, 1st Sept 97 to 2nd Dec 97.

Elapsed vessel time (in hours)	No. of vessels	Percentage
0 to 24	23	15.3%
25 to 48	108	72.0%
49 to 72	19	12.7%
Total	150	

The average time of vessels at berth from berthing to deberthing is about 35.3 hours (see Figure 2.6). This indicates the waiting time of vessels at berths for exchange of containers and it is of primary interest to the shipping lines (BTCE, 1996). However, this elapsed time requires a further break down of vessel time at berths to understand the reasons for registering higher vessel times. Figure 2.6 shows vessel registering non-operational critical delays (delays before or after exchange of containers to or from vessels) of about 6.9 hours which means vessels are not working whilst at berths. Non-operational delays can be presented by four measures, namely the time between berthing and labour boarding, port-wide industrial dispute, no labour rostered, and the time between labour moving ashore and the vessel sailing. It is found that delay the between vessel berthing and labour boarding has a significant impact on vessel output. It is observed that the delay before labour boarding is about 4.8 hours with minimum delay of 0.40 hours and maximum delay of 44.5 hours. The possible reason for such delay is that there no immediate supply of labour to service the berthed vessel. Other measures are completion-to-sailing delays (e.g. time difference between the exchange (including locking, lashing etc.) finally completing and the vessel sailing) from berths, which are observed at an average of 2.1 hours with minimum delay of 0.1 hours and maximum delay of 20.6 hours. The next immediate indicator is the average time that labour is available for vessel for pre-arrangement of container exchange.

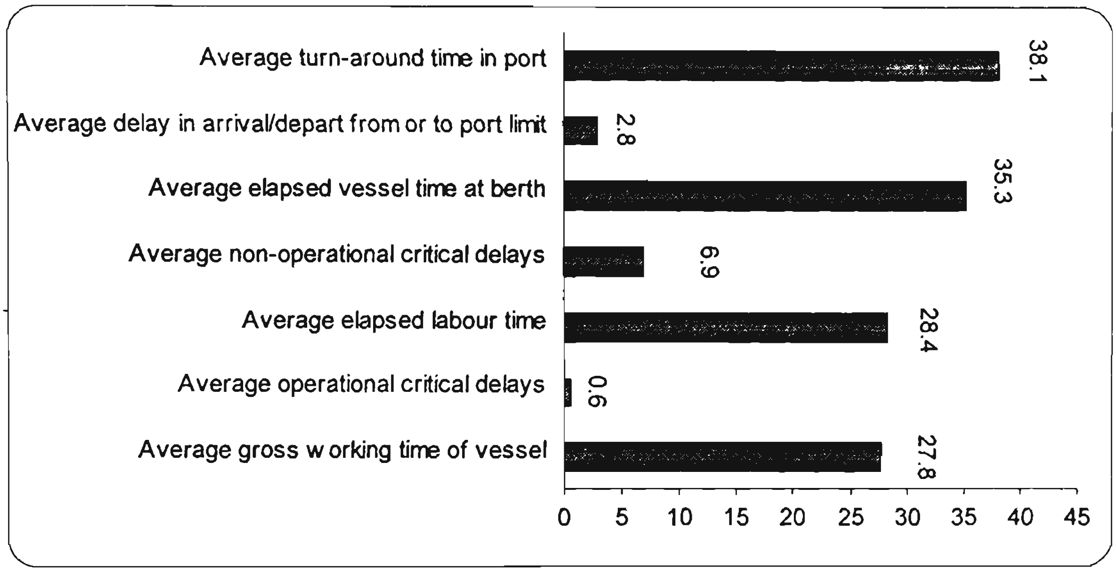


Figure 2.6. A statistical comparison of vessel times at terminal (hours).

This is usually measured after deducting all non-operational delays from the elapsed vessel time i.e. elapsed berth time. It is observed to be 28.4 hours, although this value does not provide the full explanation of shortcomings unless one analyses the range of activities by further subdivision of elapsed labour time. One can see from Figure 2.6 that vessels have registered operational critical delays of an average of 0.6 hours. Operational critical delays of vessels are often called vessel-working delays by terminal operators and they include rostered labour with-held after exchange has started, shift change between mid night and day shifts, working ramp only on RO RO vessels, booming up and down for vessels berthing or sailing, smokes/meal breaks, break bulk cargo, vessel delays (e.g. defective lids) and weather delays. To detect the precise causes of the operational delays, one further illustrates these delays by the time between labour boarding and the actual commencement of exchange and the time between completed exchange and labour going ashore. However, the vessels typically register very low operational delays in both cases. The time between labour boarding and commencement of exchange is 0.35 hours. Similarly the time between completing an exchange and labour going ashore is about 0.25 hours. There are seven causes of delays specified by the terminal operator, which are discussed in later sections.

The average gross working time at berth is observed to be 27.8 hours with a minimum time of 9 hours and a maximum time of 59.50 hours and this indicates the actual time spent in container handling operations by a vessel (see Figure 2.6). It is numerically the same as gross crane time if one crane is assigned to the vessel throughout the exchange. The gross working time of a crane is calculated by deducting all operational critical delays from the elapsed labour time. However, it is the same as the time between actual commencement of exchange and completion of exchange of containers to or from vessels.

2.5.2. Indicators of productivity

Performance measures that indicate the productivity of container-handling operations are required. The frequently used measures are:

- Vessel output per 24 hours in dock. This is typically of 400 containers/24 hour;
- Container per vessel working hour. This is observed as an average of 23 containers/hour;
- Container per vessel hour at berth. This is an average of 18 containers/hour;
- Container per labour working time. This is an average of 22 containers/hour;
- Container per vessel hour in dock. This is an average of 17 containers/hour.

It is seen from the above calculated values that the gap between 18 containers per hour at berth and 22 containers per vessel working hour points to a waste of time at the berth, when a vessel is not operated. The reasons why the vessels registered a considerable amount of non-operational critical delays, which is an average of 4.8 hrs have been established. The underlying causes are delays in boarding the vessel, no labour rostered, and port-wide industrial stoppages. However, no labour being rostered to the vessel is the dominant factor among all the underlying causes of non-operational delays.

2.5.3. Berth occupancy measures

Berth occupancy indicates the level of berth facilities which are utilised over a given time period and occupancy values are presented in Table 2.7. Individual berth occupancy is a highly significant indicator, and the values in Table 2.7 demonstrate berth 3 is the most highly used for exchange and it recorded a high berth occupancy. However a low occupancy, as noted in the case of berth 4, implies under utilisation, but it does not provide any specific answer to the underlying reasons for low or high values. One can conclude from overall berth occupancy of the terminal i.e. 56.12% that the terminal is not congested by the vessels.

Table 2.7. Berth occupancy values for a period from 1st Sept to 2nd Dec 97.

Terminal berth	Berth occupied in hours	Berth occupancy
Berth no. 1	1241.59	56.84%
Berth no. 2	1195.35	54.73%
Berth no. 3	1294.14	59.25%
Berth no. 4	1172.64	53.69%
Total	4903.72	56.12% (average)

2.5.4. Quay cranes measures

The performance of container handling will largely determine the quality of service provided by the terminal operators to the berthed vessel. The following indicators are required to measure the effectiveness of container exchange between vessel and shore, namely:

- Gross quay crane time;
- Net quay crane time;
- Containers/net quay crane hour;
- Quay cranes' intensity.

Gross quay crane time is the time measured from the time a crane commences its exchange to the exchange of the last container, which is an average of 36.43 hours as shown in Figure 2.7.

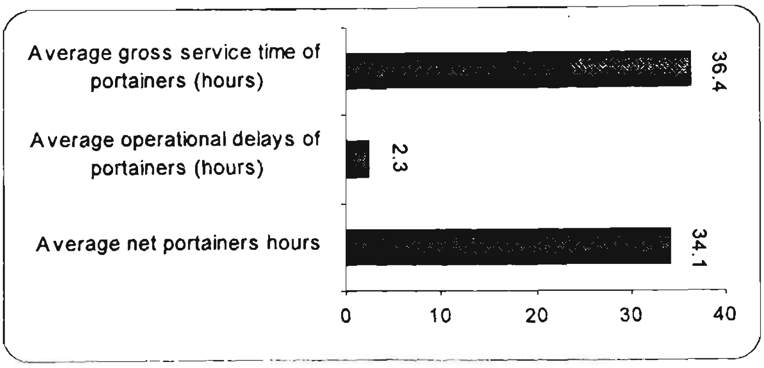


Figure 2.7. Statistical comparison of quay crane performance indicators.

For example if two quay cranes are assigned to a vessel then the total gross working time is the sum of individual gross time of quay crane for that vessel. Due allowance has been made for crane operational delays to measure the net quay crane hour. The average container-handling rate per net crane hours is 18.00, which is the same as the key performance indicator (KPI). The KPI is the benchmark used by the terminal for each vessel, but this is not the most accurate method, because in the past it was 18 container per hour and then 19 container per hour for all vessels. Now the management has set KPI on an individual vessel basis and it is adjusted on regular basis for monitoring of vessel productivity.

The quay cranes' intensity, another performance indicator, can be determined by net quay crane hours divided by the gross service time of vessel and indicates the average quay cranes used per vessel. It is found to be an average of 1.43 quay cranes per vessel.

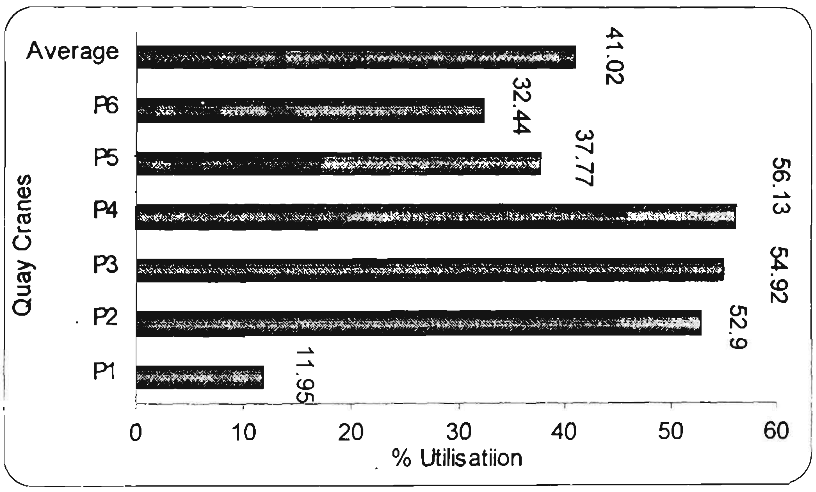


Figure 2.8. Statistical comparison of individual quay crane utilisation and average quay crane utilisation.

Figure 2.8 suggests that there is considerable under utilisation of quay crane capacity available at the container terminal. The main underlying factors influencing the operational working delays of vessel are clearly identified in the above sections. However breakdown of quay cranes, the major cause of slow down of container handling operations, has not been taken into consideration in calculating net crane hours.

2.6. The nature of deduction factors

Operators of container terminals calculate performance indicators in many different ways. The problem is that they calculate the net working times of various parts of their operations using different criteria. For example, a quay crane may be assigned to a vessel for 16 hours, but it may not have been operating for all of that time, it is possible that its operation ceased as a result of a breakdown, say. Some operators take account of such breakdowns when calculating productivity, but others do not.

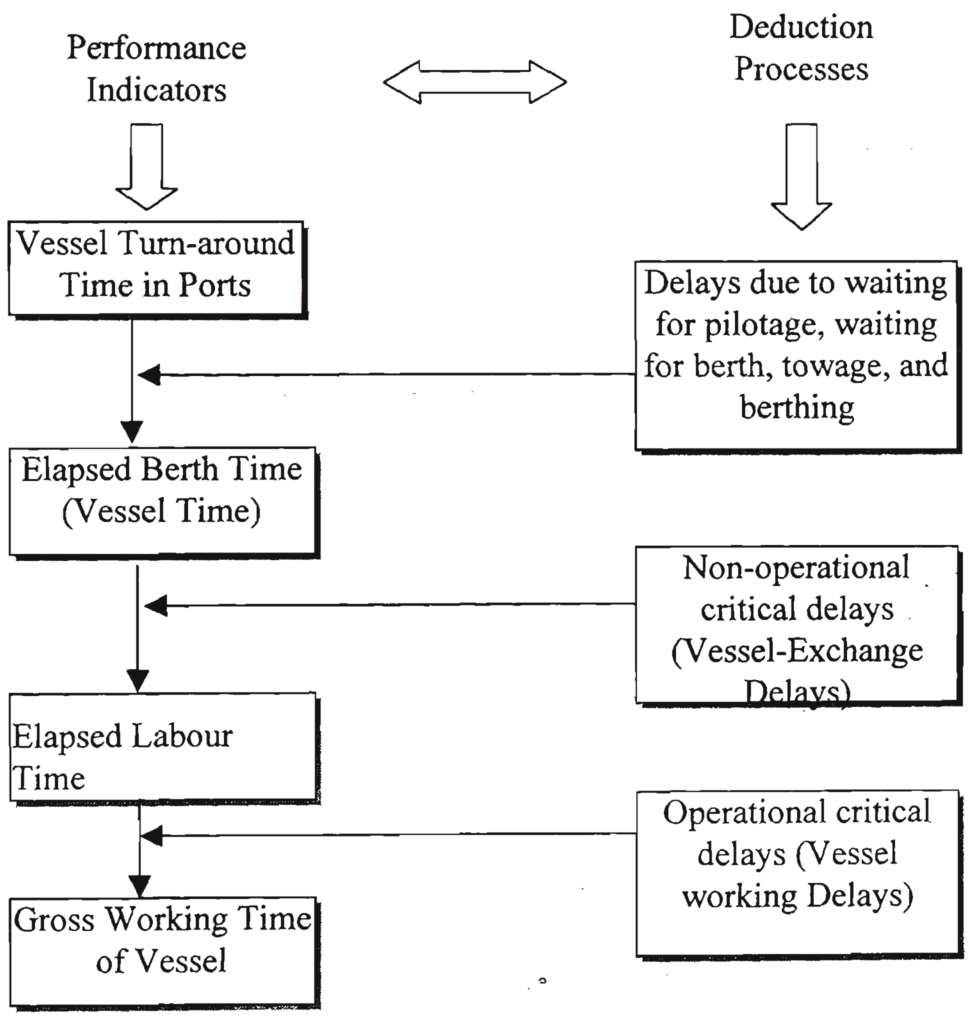


Figure 2.9. Performance indicators and delays used for a vessel at West Swanson container terminal, Melbourne.

This clearly makes comparisons between operators very difficult. In this subsection we shall consider some of these deduction factors such as meal breaks, raising the booms of the cranes to facilitate the passage of other vessels, breakdowns and so on. The deduction factors affecting the container terminal productivity can be sorted into two major families:

- Vessel delays
- Quay crane delays

The categorisation of vessel and quay crane deductions was carried out in West Swanson container terminal located in Melbourne. These time deductions are associated with the most commonly used performance indicators such as vessel turn-around time in port, elapsed berth time, elapsed labour time, net crane time, container per net crane hour, and crane intensity as shown in Figures 2.9 and 2.10.

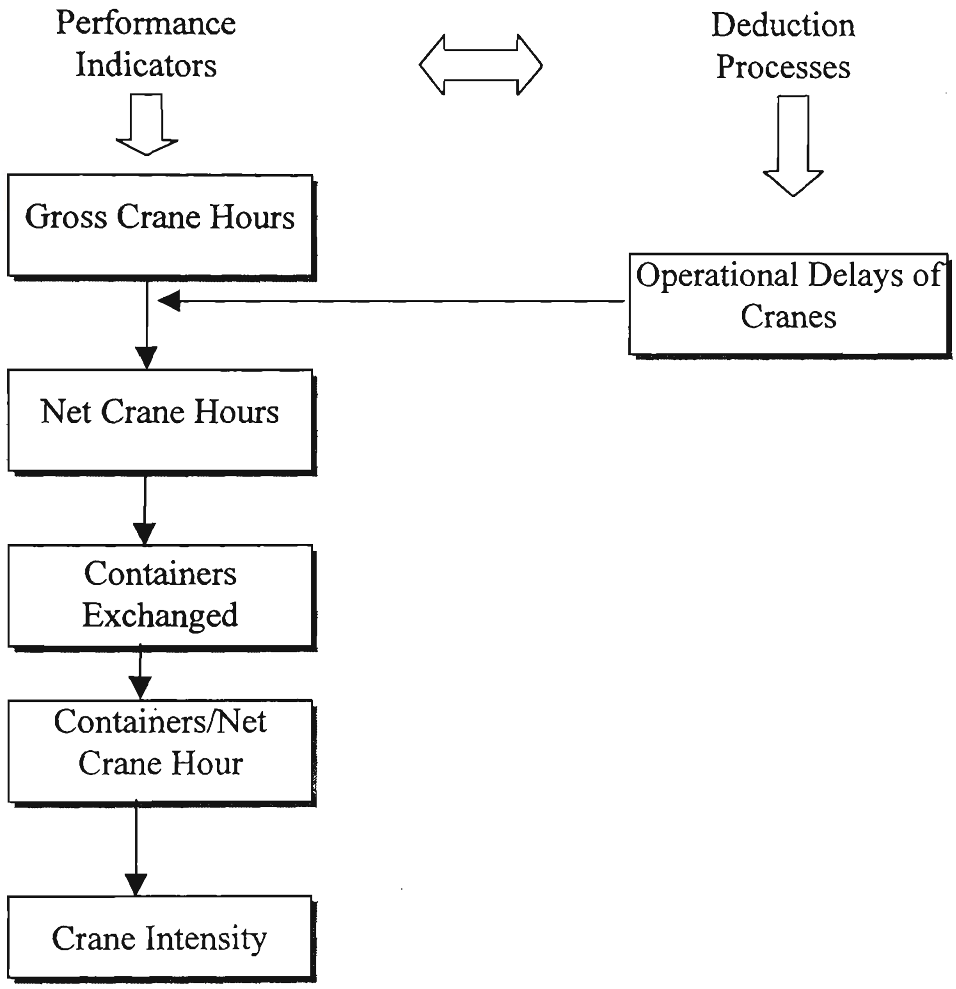


Figure 2.10. Performance indicators and delays used for quay crane at West Swanson container terminal, Melbourne.

2.7. Vessel delays

The vessel delays can be critical or non-critical delays. Critical delays automatically result in stopping all cranes handling containers for the whole operation of the vessel whereas non-critical delays stop container handling by one or more cranes, but at least one crane continues working. Non-operational delays are deducted from the elapsed labour time to get the gross service time of a vessel. Elapsed labour time is also considered as operational time or as gross working time in many other terminals (Robinson, 1985). However gross working time of a vessel is the time between commencement of exchange and completion of exchange of containers.

2.7.1. Non-operational delays

A non-operational delay is one that occurs before or after the exchange of containers to or from a vessel. Such delays may arise as a result of staff not being assigned to a vessel at the appropriate time, the vessel being unable to depart from the berth because of mechanical failure of the vessel and so on.

These delays of vessels are also critical and fall into four types of delays. These are identified as delays in boarding the vessel, completion-to-sailing time, no labour rostered, and a port-wide industrial dispute. Delays in boarding the vessel is the time difference between the vessel berthing and labour boarding the vessel for the first time or at the agreed commencement time, whichever is earlier. Delays for no labour rostered to vessel accounts for the time that labour is not allocated to work the vessel (e.g. no labour rostered on evening shift and the vessel remains idle). The delay in completion-to-sailing is the time difference between the exchange finally completing and the vessel sailing. This includes the change of shift from mid-night to day shift, if the ship loading or unloading operations are completed. A typical example of deduction processes for non-operational critical delays at West Swanson container terminal is illustrated in Table 2.8.

Table 2.8. A typical example of deduction processes of vessel non-operational critical delays at West Swanson container terminal.

Trade	Vessel	Category	Date	Shift	Delay reason	Critical (hrs)
OOCL	OEY Envoy	Non-operational	30-Oct-97	Night	No labour rostered	0.08
			31-Oct-97	Night	Completion-to-sailing time	1.50
			01-Nov-97	Night	Completion-to-sailing time	2.15
					Total	**3.73** hrs

2.7.2. Operational delays

Operational delays are defined as those that arise during the transfer of containers to or from a vessel. These are delays which stop the crane-gang in question. They may stop all crane gangs on the vessel at the same time, or some cranes may be stopped whilst others carry on working. Such delays are due to smoke or meal breaks, the booms of quay crane being raised and lowered to accommodate the movements of other vessels and so on. These can be classified as critical. Critical delays are occur when all quay cranes stop handling containers for the entire vessel. If there is a critical delay in the operations the time of the delay is deducted from the total time of the process when calculating performance measures. The idea is that a critical delay is largely beyond the control of management, therefore such delays should not reflect poorly on their performance.

Critical operational delays are related to boom up/down of cranes for other vessels, award shift break (1st to 2nd shift), delays caused by the vessel, smoke/meal break, handling break-bulk cargo, ramp work for RO RO vessels, and rostered labour withheld respectively. Adverse weather also comes under operational-critical delays. Adverse weather results from excess temperature as defined in enterprise bargaining agreement/awards or heavy rain, thunder storms, strong winds, fog or any other weather condition which results in an unsafe working environment. An operational delay of a vessel includes the change of shift between mid night and day shift, if not worked. For example the container-handling operation may cease due to the handling of break-bulk cargo, or rostered labour is withdrawn from working containers for a shift or part of a shift. This may be the result of using the crane gang to lash another vessel to meet its earliest time of departure (ETD), using the labour from a RO RO weather-deck to assist on the ramp.

Table 2.9. A typical example of deduction processes of vessel operational delays at West Swanson container terminal.

Trade	Vessel	Category	Date	Shift	Delay reason	Critical
OOCL	OEY	Operational	30 Oct 97	Day	-	-
				Afternoon	Boom up/down for other vessels	0.30
			31 Oct 97	Night	Boom up/down for other vessels	0.40
				Day	-	-
				Afternoon	Handling break-bulk cargo	0.50
			01 Nov 97	Night	Boom up/down for other vessels	0.30
					Smoke/meal break	0.80
					Total	**2.30** hrs

Table 2.10. A typical example of calculation of vessel time and rates at West Swanson container terminal.

Trade	Vessel	Performance indicators	Hours	Total container exchanged	Container rate per hour	TEU rate per hour
OOCL	OEY	Elapsed vessel time	**47.23**	1245 (1645 TEU) includes export, import, DLR# and SOB*	26.36	34.83
		(-) Non-operational delays	3.73			
		Elapsed labour time	**43.50**		28.62	37.81
		(-) Operational critical time	2.30			
		Gross service time	**41.20**		**30.22**	**39.92**

Delays are also caused by vessel or agents' requirements such as stores, defective lids, and late cargo delays to the operation by smoke or meal-breaks. A typical example of

DLR: Discharge, Land, and Restow

* SOB: Shift on Board

deduction processes of operational critical delays of vessel at West Swanson container terminal is given in Table 2.9 and the calculation of vessel time in Table 2.10.

2.7.3. Operational Working delays

An operational working delay is one that occurs during normal working time and when there is no moving of containers to or from a vessel. These delays are considered as necessary delays in the part of operation.

Table 2.11. A typical example of operational working delays at West Swanson container terminal.

Vessel	Date	Shift	Delay Reason	Crane P_4	Crane P_5	Crane P_6
OEY	30 Oct 97	Day	Delay caused by need for cage		0.75	
			Handling vessel's hatch lids	0.50		
		Afternoon	Machinery breakdown		0.20	
			Delay caused by need for cage		0.20	
			Handling vessel's hatch lids	0.20	0.30	
	31 Oct 97	Night	Delay caused by need for cage	0.90	0.20	
			Handling vessel's hatch lids		0.40	0.40
		Day	Long-travel moves			0.30
			Delay caused by need for cage	0.50	0.20	0.40
			Handling vessel's hatch lids	0.20		
		Afternoon	Machinery breakdown	0.20	0.50	
			Delay caused by need for cage		0.60	
			Handling vessel's hatch lids	0.70		
	01 Nov 97	Night	Long-travel moves		0.20	
			Delay caused by need for cage	0.20	0.50	
			Handling vessel's hatch lids	0.70		
			Total	**4.10** hours	**4.05** hours	**1.10** hours

The terminal operator does not use these delays for calculating vessel times or crane rates. However, these delays are noted separately at West Swanson container terminal, Melbourne for reporting purposes and they are usually recorded against the crane in question in vessel operation report (see Table 2.11 for a typical example).

These delays may be cage-work, handling vessels' hatch lids, locking or unlocking con-locks, lashing or unlashing containers, breakdown of cranes, and crane travelling long distances from one vessel to another.

2.8. Quay crane delays

A quay carne delay is one that occurs during the crane working time. These delays are noted separately by terminal operators for calculation of net crane hours against the crane in question. In many cases, operational critical delays are also called crane delays.

Table 2.12. A typical example of deduction processes of crane delays at West Swanson container terminal.

Vessel	Category	Date	Shift	Delay reason	P_4 Crane	P_5 Crane	P_6 Crane
OEY	Operational	30 Oct 97	Day	-			
			Afternoon	Boom up/down for other vessel	0.30	0.40	
				Handling break-bulk cargo		0.50	
			Night	Boom up/down for other vessels	0.40		0.40
				Handling break-bulk cargo			0.80
			Day	-			
			Afternoon	Handling break-bulk cargo	0.50	0.50	
			Night	Boom up/down for other vessels	0.30		
				Total	**1.50** hrs	**1.40** hrs	**1.20** hrs

These delays are caused by vessels (e.g. defective lids, stores, and waiting for container), boom up/down of quay cranes to accommodate the movements of other vessels, smoke/meal break, handling break-bulk cargo, and weather. However, crane breakdown delays are not used for calculating of crane productivity, but they are noted separately as working delays. A typical example of deduction processes of crane delays at West Swanson container terminal is described in Table 2.12 and calculation of crane operating times is given in Table 2.13.

Table 2.13. A typical example of calculation of crane operating times at West Swanson container terminal.

Vessel	Performance indicators	P4 Crane	P5 Crane	P6 Crane	Total
OEY	Gross crane hours	39.50	28.50	3.50	71.50
	Less delays	1.50	1.40	1.20	4.10
	Net crane hours	38.00	27.10	2.30	67.40
	Containers exchanged	761	428	56	1245
	Containers/net crane hrs	20.03	15.79	24.35	**18.47**
	TEUs exchanged	1016	567	62	1645
	TEUs/net crane hr	26.74	20.92	26.96	**24.41**
	Crane intensity	**1.64**			

2.9. Performance measures in Australian and Asian container terminals

It is noted that the managers of container terminals have many different methods of calculating productivity. The differences arise principally from the deductions that they apply to the total operating times for their various operations. In an attempt to quantify these differences a questionnaire was sent to 17 and 48 organisations within Australian and Asian container handling industries respectively. The questionnaire required respondents to supply information on the deduction factors they actually use. In Australia, one questionnaire was sent back due to having an incorrect address and two questionnaires were sent back because the recipients had no container handling operations. Overseas, two questionnaires were sent back because they were incorrectly addressed. The total response received was six and eighteen from the Australian and overseas terminal operators respectively. Therefore, the percentage of response in Australia was 35.29% and the percentage of response from overseas (Asia) was 37.5%. Tables 2.14 and 2.15 show the countries selected in Asia and the states in Australia for this study. The terminals in Australia and Asia were assigned identification codes (from AU1 to AU6 and A1 to A18) for confidentiality.

Table 2.14. Selected Asian countries surveyed.

Serial no.	Country/place of locations	Major terminals/ports selected	Terminals/ports responded
1	Bangladesh	1	-
2	China	2	-
3	Fiji	2	1
4	Hong Kong (PRC)	2	1
5	India	4	-
6	Indonesia	3	2
7	Japan	6	1
8	Myanmar	1	-
9	Malaysia	3	-
10	New Zealand	10	6
11	Papua New Guinea	3	-
12	Pakistan	1	1
13	Philippines	2	2
14	South Korea	2	-
15	Singapore	1	-
16	Sri Lanka	1	1
17	Thailand	2	2
18	Taiwan (PRC)	2	1
Total		48	18

Table 2.15. States surveyed in Australia.

Serial no.	States/place of locations	Major terminals/ports selected	Terminals/ports responded
1	Victoria	4	2
2	New South Wales	4	1
3	Northern Territory	1	1
4	Queensland	2	1
5	Western Australia	2	-
6	Tasmania	2	1
7	South Australia	1	-
Total		17	6

2.10. Comparison of vessel non-operational delays in Australia and Asia

All container terminals reported having a different categorisation of delays for the vessels' non-operational delays. Figure 2.11 shows that half of the terminals in Australia, 50.00%, used all four delays to estimate elapsed labour time; 16.67%, used delays in completion-to-sailing time, and 16.67%, used delays in boarding vessel, completion-to-sailing and no labour rostered. However, in one case, the container terminal is using 'other delays', which are recoverable costs. It was not clear why this terminal was using recoverable costs for non-operational delays of vessel.

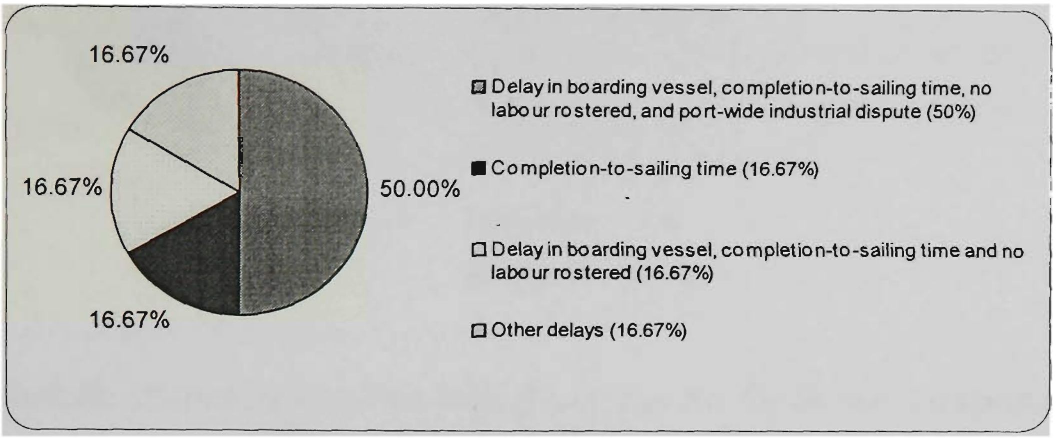


Figure 2.11. Characteristics of deduction processes of vessel non-operational delays at Australian container terminals.

Figure 2.12 shows the that majority of terminals, 16.67%, used delay in boarding the vessel and completion-to-sailing time to discriminate between elapsed labour time and elapsed vessel time. The same figure, 5.56% of terminals, used delay in boarding vessel and port-wide industrial disputes to estimate elapsed labour time; 16.67% terminals used all four delays as described in section 2.7.1, 11.11% terminals used completion-to-sailing time, and 11.11% terminals used other delays. Under "other delays" terminals reported that non-operational delays also depend on tide and shift systems with long waiting hours. However, they did not report anything about these four delays. In the same figure, 22.22% terminals did not respond to this question and it may be that they do not measure these delays. In only one case (5.56%), the terminal operator is using only delay in boarding vessel. In another two cases (5.56% and 5.56%), terminals are using delays in boarding the vessel, completion-to-sailing time and no labour rostered, and no labour rostered, completion-to-sailing time and port-wide industrial dispute as measures of non-operational delays.

Figure 2.13 shows the statistical comparison of use of operational delays between Australian and Asian container terminals

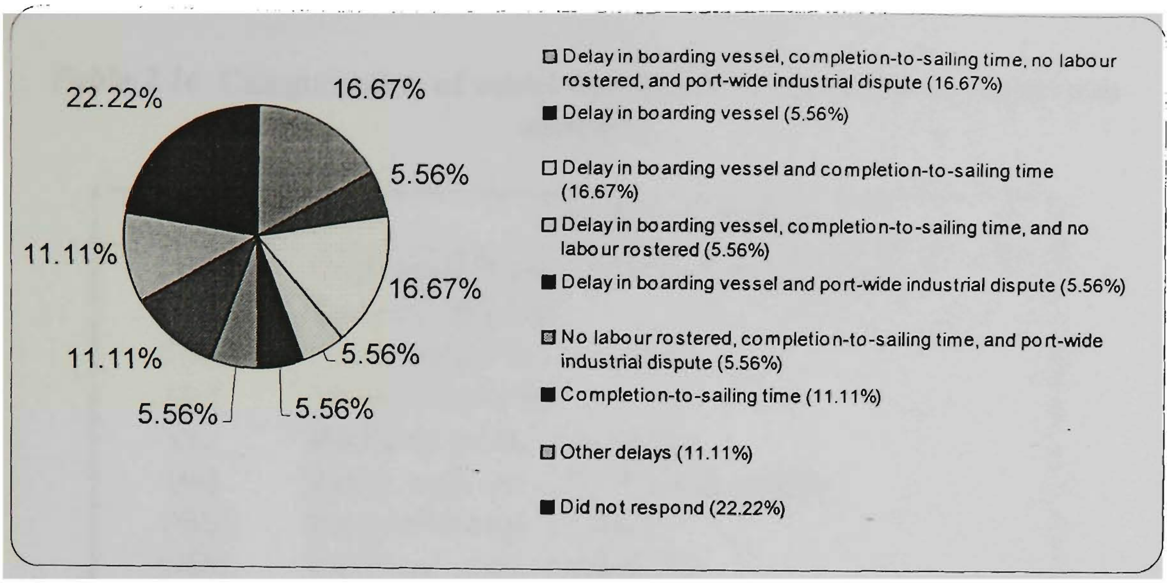


Figure 2.12. Characteristics of the deduction processes of vessel non-operational delays at Asian container terminals.

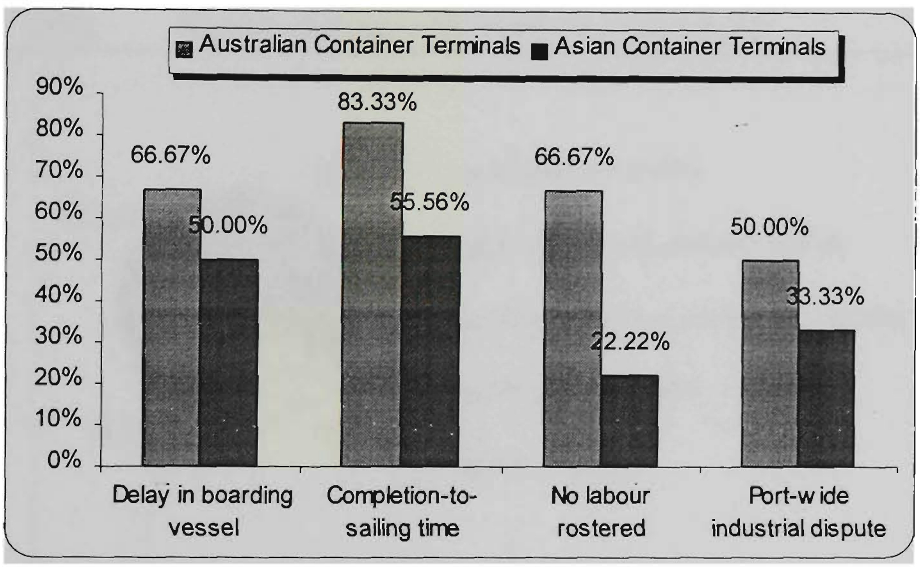


Figure 2.13. Statistical comparisons of use of non-operational delays between Australian and Asian container terminals.

2.11. Comparison of vessel operational delays in Australia and Asia

The representatives of the container terminals were asked to state which delays they were considering as vessel working delays whilst the vessel was alongside a berth. All terminals in Asia and Australia reported having eleven delays for categorisation, which is summarised in Table 2.16. Figure 2.14 shows 33.33% of terminals in Australia are considering all eleven delays to estimate gross service time from elapsed labour time. The most common delays among Australian container terminals are delays caused by the vessels. In Australia, weather related delays were reported during high winds which preclude the cranes from working, and temperatures of more than 38 degrees Celsius.

Table 2.16. Categorisation of vessel operational working delays at container terminals.

Serial No.	Category of Delays
(i)	Quay crane boom up/down for other vessel
(ii)	Award shift break
(iii)	Delay caused by the vessel
(iv)	Smoke/meal break
(v)	Handling break-bulk cargo
(vi)	Ramp work only (for RO RO vessel)
(vii)	Rostered labour withheld
(viii)	Handling vessel's hatch lids
(ix)	Delay caused by need for cage
(x)	Conlocking and lashing work
(xi)	Weather related delays
(xii)	All eleven delays [from Sl. No. (i) to (xi)]

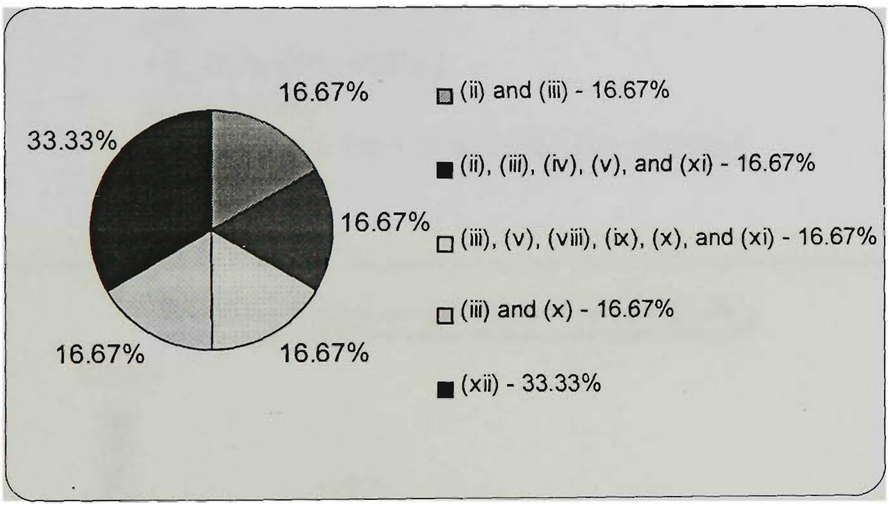


Figure 2.14. Characteristics of deduction processes of vessel operational working delays at Australian container terminals.

Table 2.17 shows that all terminals in Asia categorized different deduction of time delays except two terminals (A7 and A16) where they used the same delays. The most common delays among Asian container terminals are weather related delays and quay crane boom up/down for other vessels. In one case, the terminal operator (A7) does not consider smoke/meal break as delays because they are during continuous shift times. In another case, the terminal operator (A3) reported that the primary reason of labour withheld by the management is due to operational reasons. Figure 2.15 shows a statistical comparison of use of operational delays between Australian and Asian terminals.

Table 2.17. Characteristics of deduction processes of vessel operational working delays at Asian container terminals.

% of terminals	Deduction processes of vessel operational working delays used in Asia
5.56 (A8)	(i), (viii), and (xi)
5.56 (A9)	(i), (iii), and (xi)
5.56 (A2)	(i) and (xi)
5.56 (A5)	(i), (iii), (viii), (x), and (xi)
5.56 (A6)	(i), (ii), (iii), (iv), (v), (vi), (viii), (x), and (xi)
11.11 (A7 and A16)	(i), (iii), (v), (viii), (ix), (x), and (xi)
5.56 (A13)	(i), (ii), (iii), (iv), (viii), and (xi)
5.56 (A12)	(i), (iii), (x), and (xi)
5.56 (A11)	(i), (ii), (iv), (x), and (xi)
5.56 (A14)	(ii) and (x)
5.56 (A15)	(ii), (iii), (iv), and (xi)
5.56 (A17)	(ii)
5.56 (A18)	(ii), (iii), (iv), and (x)
5.56 (A1)	(i) and (viii)
5.56 (A3)	(iii), (iv), (v), (vii), (viii), (ix), (x), and (xi)
5.56 (A4)	(vii)
5.56 (A10)	(xii)

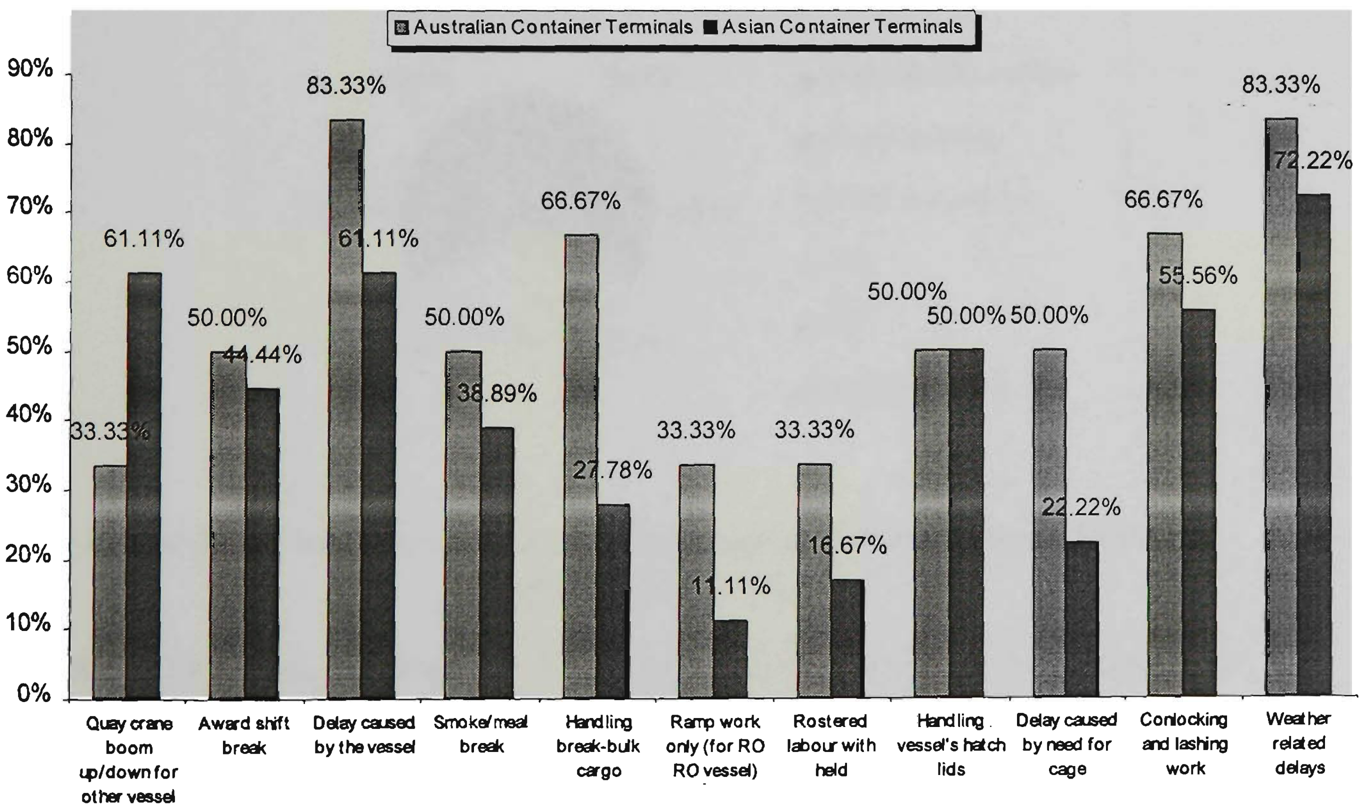


Figure 2.15. Statistical comparisons of use of operational delays between Australian and Asian container terminals.

2.12. Comparison of quay crane operational delays in Australia and Asia

The representatives of the container terminals both in Australia and Asia were asked to classify the deduction factors used for the purpose of estimating net crane hours from gross crane hours. The deduction factors are summarized in Table 2.18. As Figure 2.16 shows, all terminals in Australia have a unique way of considering deduction factors for net crane hours. In one case, the terminal used all seven delays specified in Table 2.18.

Table 2.18. Categorisation of crane delays at container terminals.

Serial no.	Category of delays
(I)	Delay caused by the vessel
(II)	Crane boom up/down for other vessel
(III)	Smoke/meal break
(IV)	Handling break-bulk
(V)	Long travel moves
(VI)	Crane break down
(VII)	Weather related delays
(VIII)	All above delays [from (I) to (VIII)]

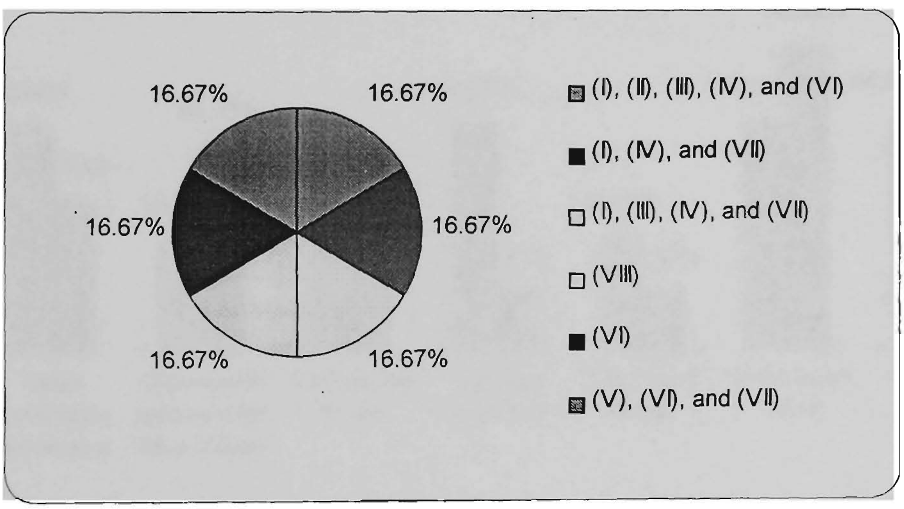


Figure 2.16. Characteristics of deduction processes of crane delays at Australian container terminals.

Table 2.19 shows, the majority of terminals, 22.22%, used delays caused by the vessel, crane boom up/down for other vessels, crane breakdowns, and weather-related delays. However, 16.67% terminals considered only breakdown as crane operational delays along with an additional 11.11% container terminals considering crane boom up/down for other vessels, smoke/meal break, and weather related delays other than crane breakdown. In contrast, the crane break down delay is common among several

Asian terminals. Figure 2.17 shows a statistical comparison of the use of crane operational delays between Australian and Asian terminals.

Table 2.19. Characteristics of deduction processes of crane delays at Asian container terminals.

% of terminals	Deduction processes of crane delays used
5.56	(I), (III), (IV), (VI), and (VII)
5.56	(I)
22.22	(I), (II), (VI), and (VII)
5.56	(I), (II), (IV), (VI), and (VII)
5.56	(I), (II), (III), (V), (VI), and (VII)
5.56	(II), (VI), and (VII)
16.67	(VI)
5.56	(II), (VI), and (VII)
11.11	(II), (III), (VI), and (VII)
5.56	(III), (V), and (VI)
5.56	(VII)
5.56	(IV) and (VI)

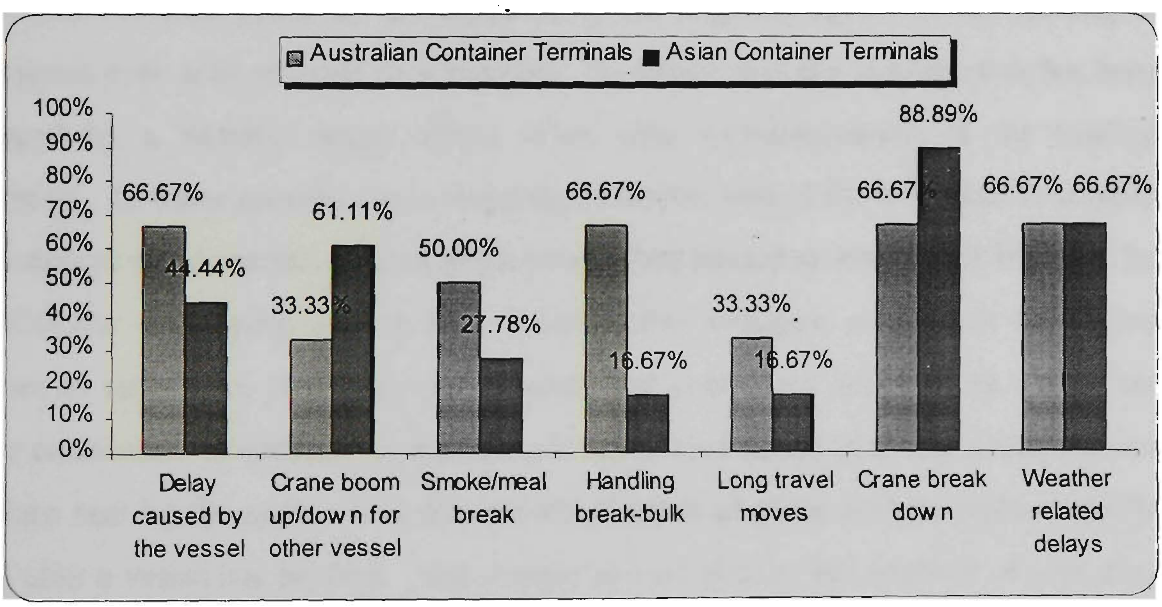


Figure 2.17. Statistical comparison of use of quay crane operational delays between Australian and Asian container terminals.

2.13. Other factors influencing the handling of containers

As well as the usual specified delays of terminals there is a great number of factors influencing the vessel and crane performance. These are discussed with reference to existing conditions in a Melbourne container terminal. These are berth allocation, load plans, portainer break downs, stowage requirements, yard layout, bay plan, late receival, trim and list, lashing, cage, lid repair, and twist locks. The direct and indirect effects of these factors on performance measure are not easily determined. These factors are discussed separately.

2.13.1. Berth allocation

It is reported that vessels change their berthing whilst discharging and load exchanging. For example a vessel discharged (import containers) to North Park whilst berthed at berth number two in South Park, similarly load exchanged in South Park whilst vessel berthed at number three in North Park. In some cases vessels are on the north side whilst containers (export or import) to be loaded are still in the storage areas on south side of terminal. This leads to long runs for the straddles from North Park to South Park and vice versa.

2.13.2. Load plans

It is seen that load plans are not supplied by the shipping agents before loading of containers even after receival of containers. In some cases the loading plan has been changed by a vessel's cargo officer even after commencement of the loading operation. In some specific cases shipping lines also amend the load plan to comply with shipper requirements. For example two reefers loaded on board may be found by FESCO (i.e. a shipping line) to have incompatible voltages; as a result the master refuses to carry then load plans are created and containers amended to dischedule these containers. Sometimes containers are not loaded as per plan and contain errors in plans sent by the agent. It is also reported that load plans are not made available until after a vessel has berthed. Any change in load plan or late receival of load plan after vessel berthed will slow down loading sequence.

2.13.3. Quay crane break down

The breakdown of quay cranes is a major problem for terminals and also controls the effectiveness of container handling. Frequent breakdowns to quay cranes P_1, P_5, and P_6 are reported together with their very slow operation. Quay crane P_1 is unable to work sections of the vessel over three stacks high and P_5, and P_6 are also unable to work over four stacks high.

2.13.4. Stowage requirements/stowage plan

Misunderstandings often occur between the box operators and the central planner of container terminal who plans the stowage of containers. For example, an exporter of fresh produce may require that the reefer container is located above the deck. However, the central planner may not have been made aware of this and determined that the reefer be stowed below deck. Such a lack of communication may result in containers being handled many times. Sometimes shipping lines fail to comply with this requirement resulting in restows. In some cases it is not advisable for chilled reefers to be placed on the top and bottom tiers under deck. The top tier is subject to too much heat from the return air. Continuing problems with stack weights both on and under deck require special sequences to cope. On many occasions the deck foreman changes the stow in the hold without reference to the control supervisor or the planner with no reasons given for the changes which result in overstows. In many cases the stowage plan is changed at the last minute by a vessel's cargo officer. Sometimes lids would not close due to unplanned restows. For example containers planned on the basis of 8'6" when they were in fact 9'6" and undeclared containers 9'6" are planned as 8'6" leads to difficulty in placing lids. Several changes may be required to stowage layout to recover lost space.

2.13.5. Yard layout

Improper yard layout always affects container-handling operation of terminals. If the yard area has mixed containers destined for different ports and of mixed weights, it is very difficult to sort them out for a vessel, which needs individual selection of load boxes. Congestion or lack of space in the yard is very common which in turn slows down the vessel container handling operation. Sometimes no dump row is allocated originally and the area is not barricaded correctly before discharging of vessels' cargo.

2.13.6. Bay plan

The bay plan is usually used for import containers for determining the location of containers in the vessel. It is extremely difficult on the part of operator when the bay plan comes from another port with all commodities entered with wrong codes, because codes can not be understood by the other terminal operator. In many cases vessels are carrying other cargo, which is not mentioned in their bay plans, which creates much confusion for the destination port. Bay plans are not always up to date but terminal operators can refer to a vessel's manifest for actual description of cargo. Terminal operators also experience problems when the bay plan for import containers has numerous incorrect details and final bay plan has not been received in time from the shipping agent even after arrival of vessel.

2.13.7. Late receival of exports

Late receival of containers for export during loading of vessel has a significant effect on the vessel turn-around time. It is also impossible to do any constructive planning at the last minute if a terminal will receive containers during the loading process of vessel. Another problem occurs when clients do not check their containers before the vessel is working alongside. Sometimes a terminal experiences extremely late receival which forces the terminal operator to reopen many holds. This causes extra lid moves and creates additional sequence sheets.

2.13.8. Trim and list

This problem arises when the vessel is unable to keep in an upright position when the vessel is experiencing a loading or unloading operation, though every vessel is equipped with adequate ballast to keep the vessel in working condition whilst alongside a berth. There is no doubt that this has a detrimental effect on the exchange rate. This could be due to insufficient ballasting capability of vessels. Sometimes a vessel finds it is impossible to correct its trim and list by ballast alone. For example planners may re-sequence containers to get maximum weight to starboard thus allowing ballast to be moved to the port side of the vessel. These operations usually affect the container exchange rate of the vessel.

2.13.9. Lashing

The time that a vessel is along side a berth can be extended by lashing work after completion of exchange of containers. Lashing work performed by labour must be carried out to the vessels' satisfaction. Sometimes a vessel has insufficient lashing gear on board to lash high containers on deck as per the lash plan. This problem is more serious when a vessel has non-existent and insufficient working platforms and safety rails on out-board slots.

2.13.10. Cage, lid and twist locks

Cage work and handling hatch lids are categorized under vessel's working delays by the terminal operator. Numerous cage trips are required when there is no access under deck or no access to some holds. Lid problems are due to excessive lid movements, inflating/deflating lid rubbers adds extra time to every lid move, long delays caused by the slow attendance to the operation of the vessel's hydraulic hatch lids by the vessel's crew, and inexperienced vessel's crew in moving lids resulting in delays. Some vessels have a wide lid to each hatch. They are as wide as the bay. Due to their width the movement of straddles is limited when working bays with cranes. Twist locks on many decks which are placed upside down result in delays until the situation is remedied and this may involve shifting boxes.

2.13.11. Miscellaneous problems

Other factors that affect the performance of quay cranes and vessels are given below. These are:

- Quay cranes are waiting for straddles.
- Several bays of a vessel require only a small exchange of containers.
- Repairs to bay cell guides of vessels causes several delays.
- Poor conditions of vessel gear causes slow operation of lashing.
- Some vessels have no pins in 40-ft cells causing disruptions in loading.
- Unofficial early knockoff has not been factored as a delay.
- Delay caused by repair gangs.
- Chemical spillage on deck causing disruption to container handling.
- Physical layout of the ship is mainly due to restricted bottom (below deck loads) resulting in slow operation of portainers.
- Hazardous declaration not received from shipping agents causes partial stoppage of lifting.
- Hatches are too close to work two portainers efficiently

- Containers worked over 4 or 5 high cause slow operation.
- New quay crane drivers causing slow operation of quay cranes.

Given the variety of factors that influence container-handling performance, it is difficult to quantify the impact of changing any one of above factors on vessel and quay crane performance.

2.14. Conclusions

The preceding discussions of vessel and quay crane outputs and productivity measures have established that terminals' performances cannot be accessed on the basis of productivity indicators alone. Performance measures and productivity indicators described in this chapter are the results of analysis of container terminal performance, which allow direct comparison between terminals.

Similarly different allocation of equipment, storage yard and berth to vessel can strongly influence expected productivity, which has been experienced in a Melbourne terminal. For example, when a vessel is berthed on the north side (berth no. 3) of the terminal and the storage yard is allocated on the south side of terminal for exchanging containers, which results in longer run for straddles. A smaller number of straddles allocated to quay cranes slows down the operation because it can not keep up with the portainers handling capacity. The reduction of vessels' non-operational delays (i.e. average delay about 5 hours between vessel berthed and labour aboard) may improve overall productivity when the vessels are berthed. Moreover, there is underutilised berth capacity at the container terminal which will enable the management to meet expected demand over next decade. Container terminal is handling approximately 2% restows of total container exchanged and it has some impact on quay crane output. It is possible to increase the throughput with improvements in productivity and changes in work practices with existing quay cranes.

A comparison of the state of practice of performance related delays at marine container terminals in Australia and Asia is provided. We concluded from the survey that categorization of deduction factors in each of the terminal surveyed are arbitrary and do not reflect that the delay categories recorded by one terminal operator are not same as other terminal operators. The categorization of time deductions should be debated before it is standardized. The productivity of each container terminal depends on deduction factors and no case is comparable with other terminals until the implementation of standard deduction processes. For example, the number of containers per net crane hour at Australian container terminals were generally below those at overseas terminals for the same vessels as reported in PC, 1998b. This suggests that vessel and crane measures are highly sensitive to the methods of calculating and reporting the deduction factors, which vary among container terminals.

Some specific vessels with insufficient space to complete lashing to vessels requirements are the subject of some arguments with terminal operators which must be clarified with some written agreement. Similarly, in future any changes to load plans sent from agents necessitating restows must be clearly spelled out, because planning disturbances are more nuisances than delays. It is very hard for an operator to access desired containers when the vessel has limited stack weight ability. It is necessary that shift staff have ready access to both light and heavy containers in order to keep stows within limits during container exchange.

Many factors such as berth allocation, load plans, stowage requirements/stowage plan, yard layout, bay plan, late receival of exports, trim and list problem of vessels, poor conditions of vessel gear, repairs to bay cell guides of vessels, unofficial early knock off, and the physical layout of vessels (i.e., due to their restricted bottom) are directly or indirectly involved during container handling operations. These factors that influence performance measures should be monitored for a simple identification of new deduction factors. Comparisons of container terminals' performance measures and underlying factors governing outputs are obviously useful to remedy the shortfalls. The next chapter will discuss a simulation approach in container terminal operations.

CHAPTER 3

A SIMULATION APPROACH TO THE OPERATION OF CONTAINER TERMINALS

3.1. Introduction

The management of a marine container terminal is a complex process that involves a vast number of decisions. It is often useful to study a model to obtain performance measures of a container terminal, since experimentation with the terminal itself would be disruptive, not cost-effective or simply impossible. Realistic models cannot be evaluated mathematically because the underlying relationships which comprise the models are not sufficiently simple to obtain exact solutions (Law, 1986). These models are studied by simulation. The most often mentioned area of research in port simulation has been in the area of terminal operations. This includes the modelling of existing terminals to improve productivity and throughput (Bruzzone and Signorile, 1998). The efficiency of present day terminal activities depends greatly on the efficiency of management logistics processes related to organisation and implementation of a corresponding flow of containers (Merkuryev *et al.* 1998).

Simulation models can be used to determine whether operational objectives will be met, identify the operational deficiencies, and they are used to propose suitable recommendations which will overcome identified deficiencies.

The main objective of this research is to determine how managers can analyse the operation of terminals starting with the operation of a gate complex and a storage yard for loading and unloading of containers on vessels using simulation. This chapter describes the methodology behind the terminal simulation and the empirical functions that quantify the relationship between the inputs and outputs of the simulation. Although empirical models are generally used in the post processing of simulations, the use of empirical models in the context of container terminal simulation is not yet established. Figure 3.1 shows the flow chart of the simulation of the West Swanson container terminal operation.

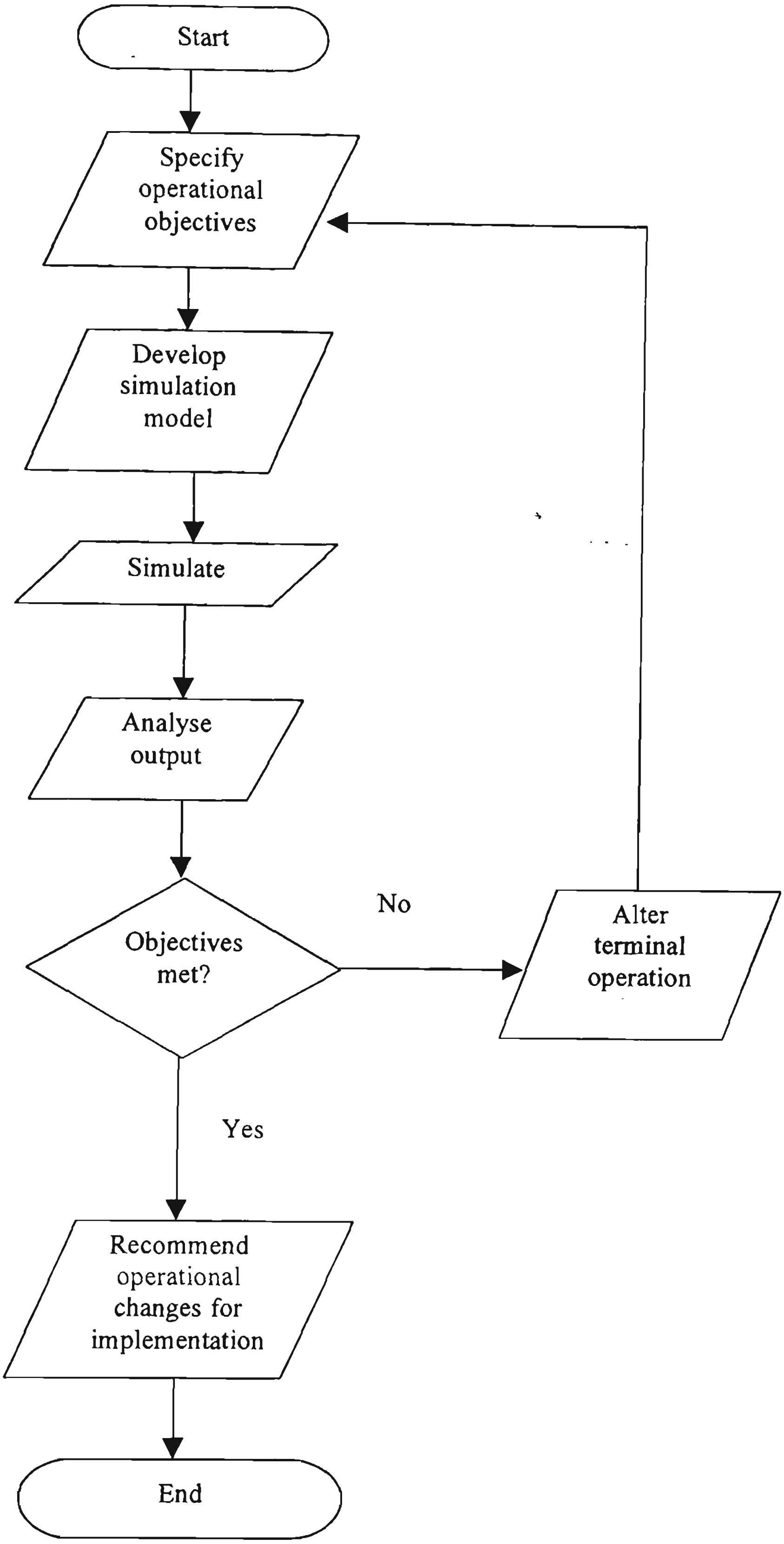


Figure 3.1. Flow chart of the simulation of West Swanson container terminal operation.

3.2. Elements of simulation analysis

Container terminal simulation is discrete, probabilistic, and dynamic, because changes occur only at discrete points in time, the variables involved are defined by an appropriate probability distribution function, and the operations of terminal are dynamic in nature. The elements of a simulation study are provided in Figure 3.2 (Hoover and Perry, 1990 and Robinson, 1994). Each element of the simulation study is discussed in the following sections of this chapter.

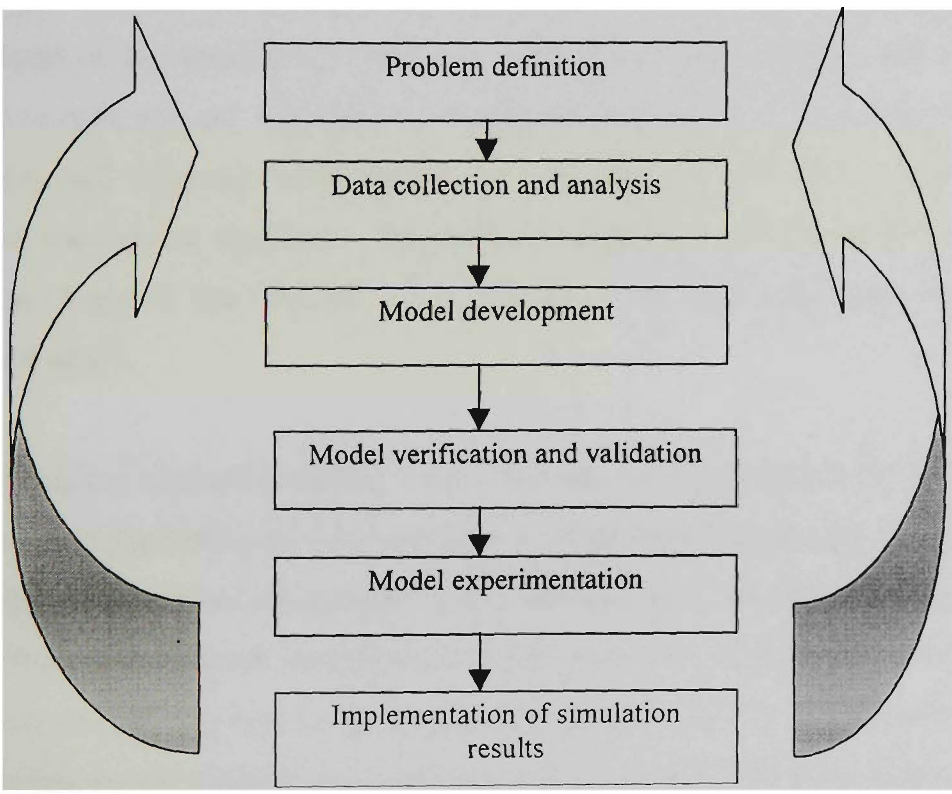


Figure 3.2. Elements of a simulation study.

3.3. Problem definition

The initial phase of the simulation is to understand the container terminal operation and to identify key performance measures. The management of P&O Ports at West Swanson Dock, Melbourne identified the general aim as being to develop a simulation model of the container terminal operation (see Appendix A). The measure or measures of performance are referred to as the objective function. The objectives are to determine the best use of gate facilities for obtaining higher throughput of road vehicles, to determine the appropriate number of straddle carriers, and to demonstrate the need to change existing handling policies. The problem definition of container terminal will be described in Chapters 4 and 5.

3.4. Data collection and analysis

Data collection and analysis form the second phase in the simulation analysis (Vincent 1998, Robinson 1994, and McHaney 1991). There is a number of ways to obtain data about the container terminal system. The data from terminal records (historical), observational data, and estimates made by operational staff were considered for use. The management of the terminal provided some useful data from their records. However, the terminal records are not sufficient to formulate the model. The system was observed during day and afternoon shift operations and gathered the data by performing time studies as the system operates. Appropriate operating staff was asked to provide the operational logic of the terminal. The details of the data collection are discussed in Chapters 4 and 5.

The fundamental choice is whether to use the data directly to drive the simulation model of the terminal operations or whether to fit a probability distribution to the existing data. The choice is based on theoretical issues and practical considerations (Pegden *et al.*, 1995). From a theoretical standpoint, the data represent what has happened in the past, which may or may not lead to an unbiased prediction of what will happen in the future. If the conditions surrounding the generation of these historical data no longer apply, then historical data may be biased or may simply be missing some important aspects of the process. If fitted probability distributions are used, it is possible to obtain values that are not possible (e.g., from the tails of unbounded distributions) or that lose important characteristics (e.g., bimodal data, sequential patterns). The collected data values are used by fitting them to probability distributions because we may not have enough historical data to drive a simulation run that is long enough to support simulation analysis. Moreover, reading a lot of data from a file typically is slower than sampling from a probability distribution.

The next step is to organise the raw data - whether for direct sampling or for fitting data to a theoretical distribution. The data usually organised in the form of histograms because they provide readily interpreted visual synopses of the continuous data.

3.4.1. Histograms

To develop a histogram we need to group the data into a number of intervals or classes and determine the number of data belonging to each class, called the interval or class frequency. There is no definitive guide for choosing the number of classes or intervals k. There are some general rules of thumb that can be used for choosing the number of intervals or classes. The following are used frequently: Sturges' rule, which states that k should be chosen according to the following formula (Law and Kelton, 1991):

$$k = \lfloor 1 + \log_2 n \rfloor = \lfloor 1 + 3.322 \ \log_{10} n \rfloor \qquad [3.1]$$

where n is the total number of data points. Another rule is the approximation rule in which k is chosen according to following formula

$$k = \sqrt{n} \qquad [3.2]$$

This rule is valid for real-valued data. Similarly for integer-valued data, k should be chosen according to following formula

$$k = (\text{maximum data value} - \text{minimum data value}) + 1 \qquad [3.3]$$

A histogram is an approximation estimate of the density function, so it is essential to select the appropriate lower and upper bounds of the histogram. The input analyser of the ARENA software (Arena user's guide version 3.5, 1998) and Microsoft Excel for analysis of histograms have been used. If the data points are interpreted as being real-valued, the histogram bounds are beyond the minimum and maximum data points. For example, the lower bound will be the largest integer that does not exceed the smallest data point, and the upper bound will be the smallest integer that equals or exceeds the largest data point. If the minimum or maximum data point is interpreted as being integer-valued, the corresponding histogram bound is adjusted so that it extends slightly beyond the minimum or maximum values. However, the ARENA input analyser interprets the number of intervals based on Equations 3.2 and 3.3. Furthermore, it is easy for visually inspecting a histogram in reference to certain density functions. However, there is no guarantee that a histogram can provide a good clue to the distributions in the absence of a definitive guide for choosing the number of intervals (k).

3.4.2. Selection of probability distributions

The types of probability distributions are shown in Figure 3.3. The theoretical distributions generate samples based on a mathematical formulation. The empirical distributions simply divide the actual data into groupings and calculate the proportion of values in each group. The continuous theoretical distributions include uniform, triangular, exponential, normal, beta, Erlang, gamma, lognormal, and Weibull which returns a real valued quantity. They are usually used to represent time-based data in a simulation model.

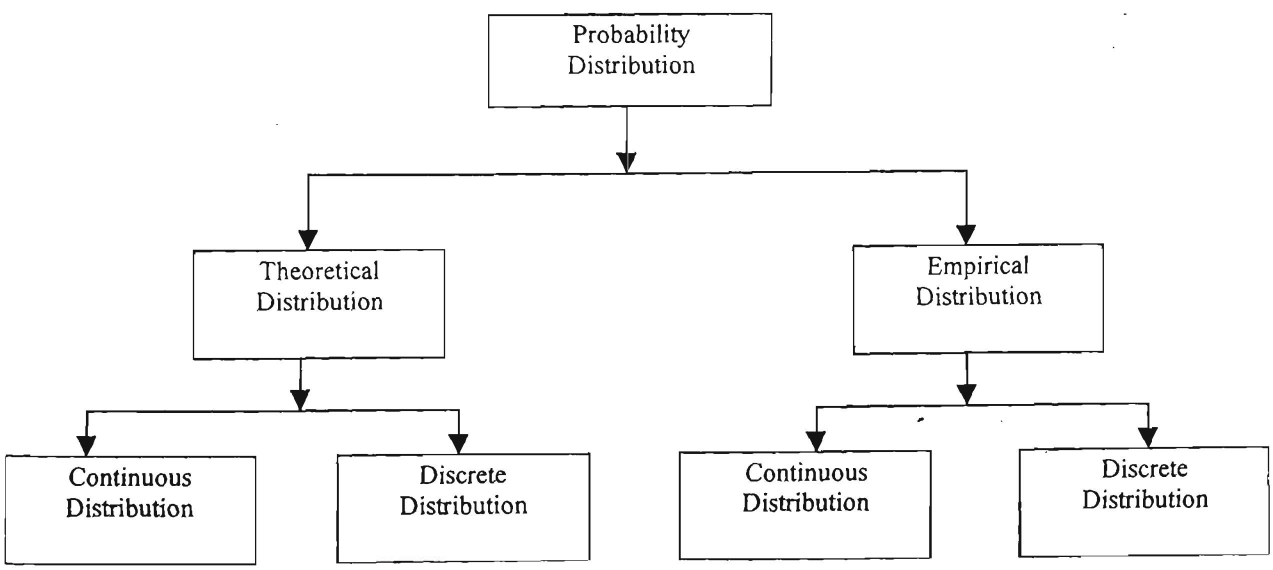


Figure 3.3. Types of probability distribution.

The Poisson distribution is a discrete distribution. It can return only integer-valued quantities. It is often used to describe the number of events that occur in an interval of time. The empirical discrete and empirical continuous distributions are defined by a series of probability/value pairs representing a histogram of the data values that can be returned. The discrete empirical distribution returns only the data values themselves, using the probabilities to choose from among the individual values. The continuous empirical distribution uses the probabilities and the values to return a real-valued quantity. It can be used in place of a theoretical distribution in cases where the data have unusual characteristics or where none of the theoretical distributions provides a good fit. The selection of a theoretical distribution to the data requires the following steps.

- Select a distribution.
- Estimate the parameter values to use for the distribution chosen.
- Determine the relative "goodness of fit" by using an appropriate method.

3.4.3. Selection of distributions

There are two critical elements to representing observed data via a probability distribution: estimating the parameters and selecting a distribution. In many cases, the quality of the parameter estimation, particularly regarding how variance is represented, is more important than the distribution chosen. There are few standard rules for making the choice of theoretical or empirical distributions. The principal method of selecting a theoretical distribution is by inspecting the histogram (see Figure 3.4).

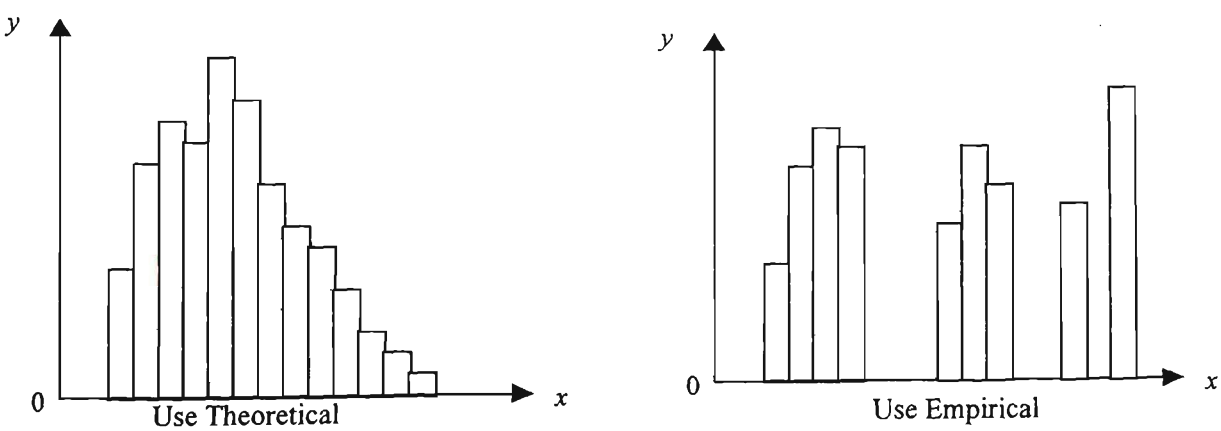


Figure 3.4. Choice of distribution based on inspecting a histogram of the data set.

If the histogram of the data appears to be fairly uniform or has a single hump and if it does not have any large gaps where there are not any values, then it may be possible to use a theoretical distribution. If there is a number of value groupings that have multimodal (many observations) or there are a number of data points that have a value that are significantly different from the main set of observations, an empirical distribution may provide a better representation of the data.

It noted earlier that there is no rigorous general agreed-upon approach to allow one to choose the best distribution. Statistical tests (such as the Chi-Square and Kolmogorov-Smirnov, mentioned below) might rank distributions differently, or changes in the number of intervals of the histogram might lead to a different choice of distribution.

3.4.4. Estimation of the parameter values of distributions

The following sections provide a short discussion of common methods by which distributions are defined or parameterised.

3.4.4.1. Theoretical continuous distribution

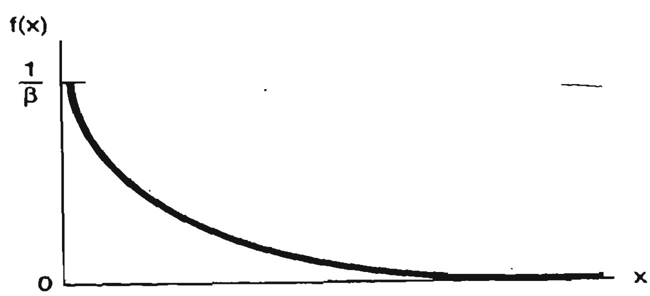
There is a number of continuous distributions in common use including uniform, triangular, exponential, Erlang, gamma, Weibull, normal, lognormal, and beta. The estimation of parameters for most of the distributions is relatively simple, although for some distributions it is quite difficult. For example parameter estimation for the Weibull distribution is not as simple as for the exponential, Poisson, normal, and lognormal distributions. In the exponential, Poisson, normal, and lognormal distributions, the sample mean and standard deviation are the basis for estimating the parameters.

For a given family of distributions, if the parameters are defined correctly, they can be classified, on the basis of their physical or geometric interpretation such as location, scale, or shape parameters. A location parameter γ specifies the x axis location point of a distribution's range of values; usually γ is the midpoint (e.g., the mean μ for a normal distribution) of the distribution's range. If the parameter changes, then the associated distributions also merely shifts left or right. A scale parameter β determines the unit or scale of measurement of the values in the range of the distribution. For any change in this parameter the associated distribution compresses and expands without altering the basic form. The shape parameter α changes the associated distribution more fundamentally than a change in location or scale. For example the parameter may alter the skewness (asymmetry) of a distribution.

Exponential Distribution

The exponential distribution has only one parameter, which is the mean. Figure 3.5 shows the shape of exponential density function. If the data set is of n observations given by $x_1, x_2, \ldots, x_n$, the mean (β) is the sample mean $(\bar{x})$ and is estimated by

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = \beta \qquad [3.4]$$



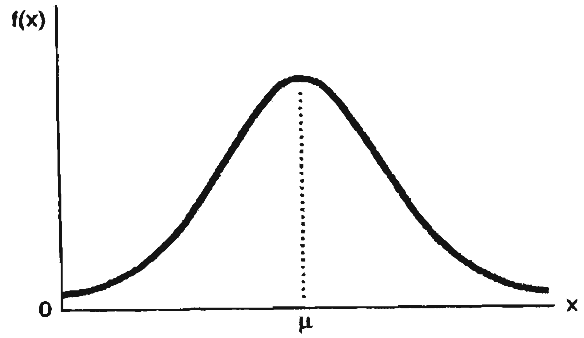
$$f(x) = \begin{cases} \dfrac{1}{\beta} e^{-x/\beta} & \text{if } x \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

Figure 3.5. Exponential (Mean) density function.

Normal distribution

The normal distribution has two parameters the mean and standard deviation (StdDev). The density function is shown in Figure 3.6. The mean (μ) is estimated by sample mean as in Equation 3.4. The StdDev (σ) is is estimated by the sample StdDev (s) given by

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1} \qquad [3.5]$$



$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\left(x - \mu^2\right)/2\sigma^2\right]$$

Figure 3.6. Normal (Mean, StdDev) density function.

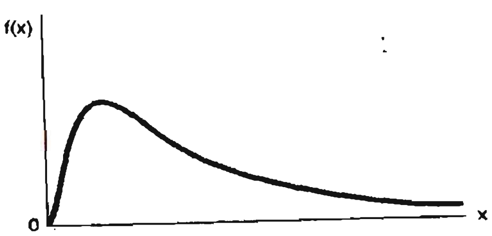
Lognormal distribution

The density function is shown in Figure 3.7. The two parameters, mean (μ) and standard deviation (σ), are defined by

$$\text{Mean} = \exp\left[\mu + \sigma^2/2\right] \qquad [3.6]$$

$$\text{Variance} = \exp[2\mu + \sigma^2(\exp(\sigma^2) - 1)] \qquad [3.7]$$

One can use sample mean and variance in the above equations to estimate μ and σ.



$$f(x) = \begin{cases} \frac{1}{\sigma x\sqrt{2\pi}} \exp\left[\frac{(\ln x - \mu)^2}{2\sigma^2}\right] & \text{if } x > 0 \\ 0 & \text{otherwise} \end{cases}$$

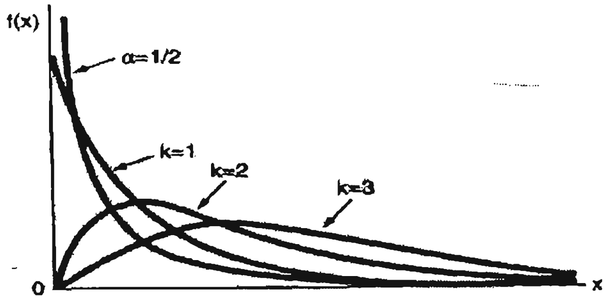
Figure 3.7. Lognormal (Mean, StdDev) density function.

Gamma distribution

The gamma distribution has two parameters, namely the shape parameter (α), and the scale parameter (β). These parameters are related to the mean (μ) and variance (σ^2) of the gamma distribution as follows:

$$\alpha = (\mu/\sigma)^2 \text{ and } \beta = \sigma^2/\mu \qquad [3.8]$$

The density function of gamma is show in Figure 3.8. We can use observed data (sample) mean and sample variance in Equation 3.8 to estimate α and β.



$$f(x) = \begin{cases} \dfrac{\beta^{-\alpha} x^{\alpha-1} e^{-x/\beta}}{\Gamma(\alpha)} & \text{if } x > 0 \\ 0 & \text{otherwise} \end{cases}$$

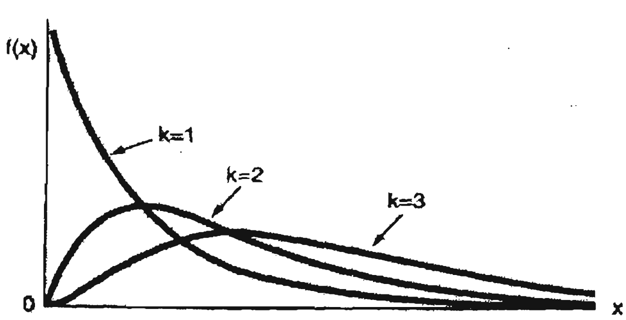
where Γ is the gamma function

Figure 3.8. Gamma (Beta, Alpha) density functions.

Erlang Distribution

The Erlang distribution has two parameters, namely the exponential mean and the number of exponential samples (k). Figure 3.9 shows the density function of Erlang distribution. This distribution is a special case of the gamma distribution in which the scale parameter, β shape parameter, α are the same as exponential mean and k. We can use Equation 3.8 given above for the gamma distribution for estimating the shape parameter, α for the Erlang distribution. The k value must be calculated to the nearest integer. The exponential mean (β) can be obtained from the relationship

$$\beta = \alpha / k \,. \qquad [3.9]$$



$$f(x) = \frac{\beta^{-k} x^{k-1} e^{-x/\beta}}{(k-1)!}$$

Figure 3.9. Erlang (exponential mean, k) density functions.

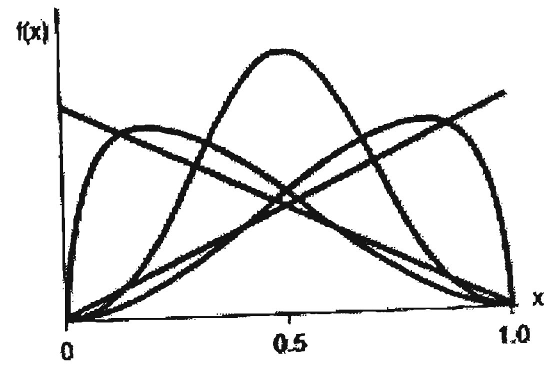
Beta distribution

There are two shape parameters given by α_1 and α_2. These parameters are related to the mean (μ), and variance (σ^2) of the beta distribution as follows:

$$\alpha_1 = \mu[(1-\mu)\mu/\sigma^2 - 1] \qquad [3.10]$$

$$\alpha_2 = \mu(1-\mu)[(1-\mu)\mu\sigma^2 - 1] \qquad [3.11]$$

The two shape parameters can be estimated by employing the mean and variance of the observed data (sample) in the above equation for the beta distribution. Figure 3.10 shows the density function of the beta distribution.



$$f(x) = \begin{cases} \dfrac{x^{\alpha_1-1}(1-x)^{\alpha_2-1}}{B(\alpha_1,\alpha_2)} & \text{if } 0 < x < 1 \\ 0 & \text{otherwise} \end{cases}$$

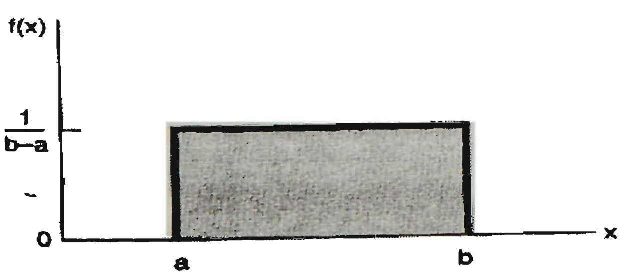
where $B(\alpha_1,\alpha_2)$ is the beta function given by

$$B(\alpha_1,\alpha_2) = \int_0^1 t^{\alpha_1-1}(1-t)^{\alpha_2-1}\,dt$$

Figure 3.10. Beta (Alpha$_1$, Alpha$_2$) density functions.

Uniform Distribution

The uniform distribution has two parameters: the minimum (*a*) and the maximum (*b*) which are both real numbers with *a*<*b*; *a* is a location parameter, *b-a* is a scale parameter. The minimum and maximum parameters for the distribution can be estimated using the smallest and largest values in the data set. If the minimum parameter is known to be zero, a better estimate for the maximum parameters in this case is the largest value in the data set times the quantity $(n+1)/n$ (i.e. n is sample size) (Pegden *et al.*, 1995). The density function of the uniform distribution is shown in Figure 3.11.

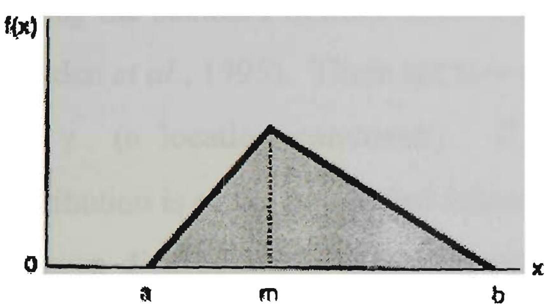


$$f(x) = \begin{cases} \dfrac{1}{b-a} & \text{if } a \le x \le b \\ 0 & \text{otherwise} \end{cases}$$

Figure 3.11. Uniform (Min, Max) density function.

Triangular distribution

The triangular distribution has three parameters: minimum (a), mode (m), and maximum (b). The parameters for the distribution specified as real numbers with $a \leq m \leq b$. The minimum and maximum parameters can be estimated by using the smallest and largest values in the data set. The mode (m) can be estimated by multiplying the sample mean by 3 and subtracting the smallest and the largest values in the data set. Figure 3.12 shows the density function of the triangular distribution.

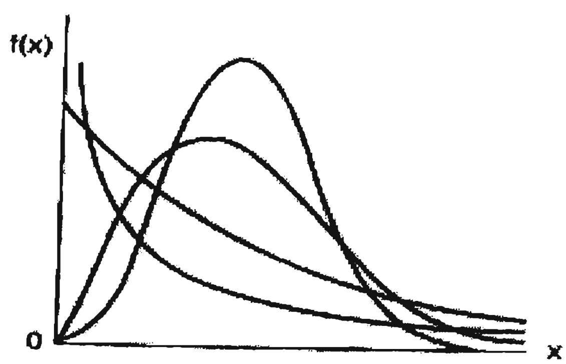


$$f(x) = \begin{cases} \dfrac{2(x-a)}{(m-a)(b-a)} & \text{if } a \leq x \leq m \\ \dfrac{2(b-x)}{(b-m)(b-a)} & \text{if } m \leq x \leq b \\ 0 & \text{otherwise} \end{cases}$$

Figure 3.12. Triangular (Min, Mode, Max) density functions.

Weibull distribution

There are two parameters in the Weibull distribution: the scale parameter (β) and the shape parameter (α). The parameters are non-negative real numbers. Unfortunately, there are no simple procedures for estimating the parameters (Pegden *et al.*, 1995). The maximum likelihood estimate for the parameters can be obtained by using a numerical method (Law and Kelton, 1991). The density function of Weibull distribution is shown in Figure 3.13.



$$f(x) = \begin{cases} \alpha\beta^{-\alpha} x^{\alpha-1} e^{-(x/\beta)^{\alpha}} & \text{if } x > 0 \\ 0 & \text{otherwise} \end{cases}$$

Figure 3.13. Weibull (Beta, Alpha) density functions.

The mean and variance of the Weibull distribution are as follows:

$$\text{Mean} = \frac{\beta}{\alpha}\Gamma\left(\frac{1}{\alpha}\right), \text{ where } \Gamma \text{ is the gamma function} \quad [3.12]$$

$$\text{Variance} = \frac{\beta^2}{\alpha}\left\{2\Gamma\left(\frac{2}{\alpha}\right) - \frac{1}{\alpha}\left[\Gamma\left(\frac{1}{\alpha}\right)\right]^2\right\} \quad [3.13]$$

Johnson Distribution

The Johnson distribution is not really a distribution, but a system for translating and scaling the standard normal distribution to obtain a wide variety of distributional shapes (Pegden *et al.*, 1995). There are four parameters in this distribution: α_1, α_2 (> 0), β (> 0), and γ (a location parameter). If the α_2 parameter is positive, then the Johnson distribution is called a bounded Johnson distribution. Similarly, if α_2 is negative, then the Johnson distribution is called an unbounded Johnson distribution. The bounded and unbounded Johnson distributions are provided in Figure 3.14. Note that this distribution has not been used in our simulation study.

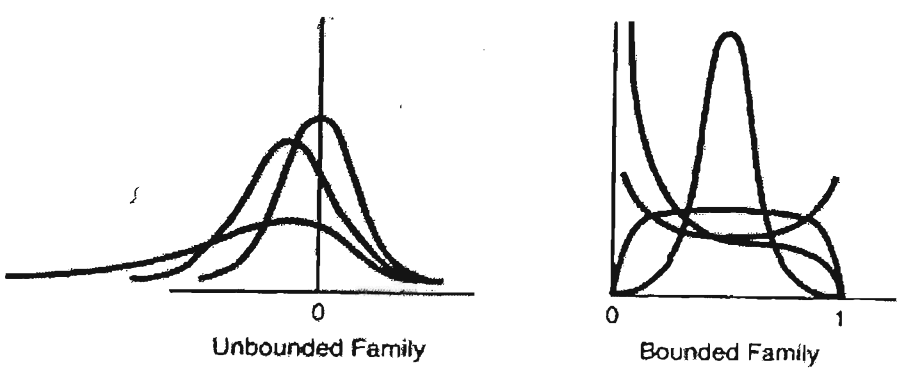


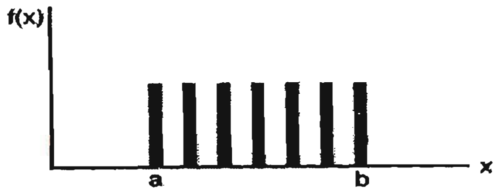
Figure 3.14. Johnson (α_1, α_2, β, γ) density functions.

3.4.4.2. Theoretical discrete distribution

Short descriptions of theoretical discrete distributions are discussed in the following sections.

Discrete uniform distribution

This distribution has two parameters *a* and *b* which are integers with $a \leq b$; *a* is a location parameter, and *b-a* is a scale parameter. The parameter *a* can be estimate as the minimum value of the data set and the parameter b can be estimate as the maximum value of the data set. Figure 3.15 shows the mass function of a discrete uniform distribution.



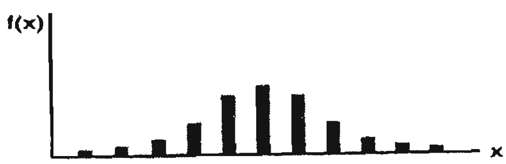
$$p(x) = \begin{cases} \dfrac{1}{b-a+1} & \text{if } x \in \{a, a+1, \ldots\ldots, b\} \\ 0 & \text{otherwise} \end{cases}$$

Figure 3.15. Discrete uniform (a, b) mass function.

Binomial distribution

A binomial distribution has two parameters, t (independent Bernouilli trials) and probability (p). These parameters can be estimated from the following relationships:

$$\text{Mean} = tp \text{ and Variance} = tp(1\text{-}p) \qquad [3.14]$$



$$p(x) = \begin{cases} \dbinom{t}{x} p^x (1-p)^{t-x} & \text{if } x \in \{0, 1, \ldots\ldots, t\} \\ 0 & \text{otherwise} \end{cases}$$

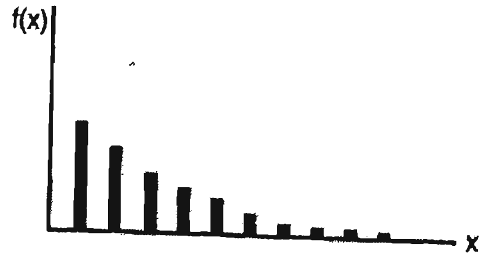
Figure 3.16. Binomial(t, p) mass function.

In the Figure 3.16, $\binom{t}{x}$ is the binomial coefficient and is defined by $\binom{t}{x} = \dfrac{t!}{x!(t-x)!}$.

Geometric distribution

The geometric distribution calculates the number of failures before the first success in a sequence of independent Bernouilli trials with probability p of success on each trial. The mass function of this distribution is shown in Figure 3.17. The distribution has only one parameter p (i.e. $p \in (0, 1, \ldots)$). The parameter p can be estimated from the following relationship

$$\text{Mean} = \frac{1-p}{p} \text{ and Variance} = \frac{1-p}{p^2} \qquad [3.15]$$

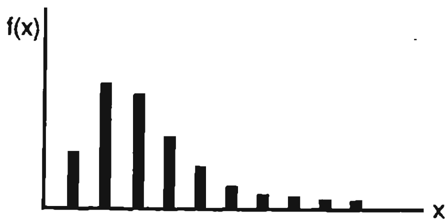


$$p(x) = \begin{cases} p(1-p)^x & \text{if } x \in \{0, 1, \ldots\} \\ 0 & \text{otherwise} \end{cases}$$

Figure 3.17. Geometric (p) mass function.

Poisson distribution

A Poisson distribution has one parameter, its mean, λ. If the data set is of n observations such as $x_1, x_2, \ldots, x_n$, the parameter (λ) is estimated by $\bar{x} = \frac{\sum x_i}{n}$. Figure 3.18 shows the mass function of Poisson distribution.



$$p(x) = \begin{cases} \dfrac{e^{-\lambda}\lambda^x}{x!} & \text{if } x \in \{0, 1, \ldots\} \\ 0 & \text{otherwise} \end{cases}$$

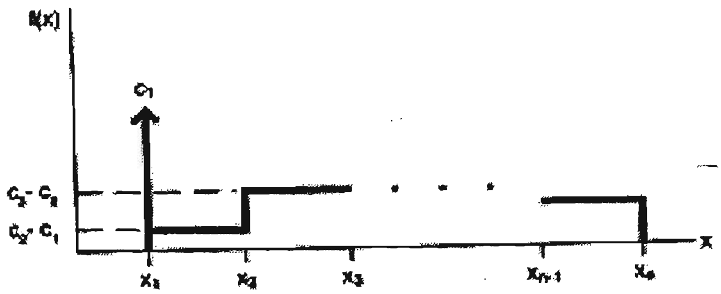
Figure 3.18. Poisson (Mean) mass function.

3.4.4.3. Empirical distributions

An empirical distribution can be used when none of the theoretical distributions provides a good fit or if the data have unusual characteristics.

Empirical continuous distribution

The empirical continuous distribution uses the probabilities and the values to return a real-valued quantity. The disadvantage of specifying this distribution is that random values are generated between the smallest value (x_1) and the largest value (x_n) and do not allow random values to be generated beyond the largest observation. The distribution parameter is defined by a set of n discrete values (denoted by x_1 x_2, ..., x_n) and the cumulative probabilities (denoted by c_1 c_2, ..., c_n) associated with these values. The Figure 3.19 gives an illustration of continuous distribution function.



$$f(x) = c_j - c_{j-1}$$

where $c_0 = 0$ and j is the smallest index such that $x < x_j$

Figure 3.19. Continuous (CumP$_1$, Val$_1$,....) distribution function.

The cumulative probability (c_j) for x_j is defined as the probability of obtaining a value that is less-than-or-equal to x_j. The distribution is assumed to be piecewise linear between the n discrete values. Because c_j is the cumulative probability, $c_1 = 0$ and $c_n = 1$. Figure 3.20 illustrates the continuous, piecewise linear distribution function.

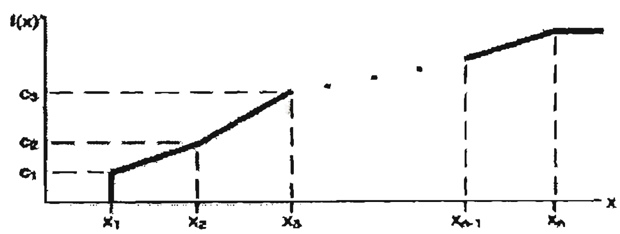
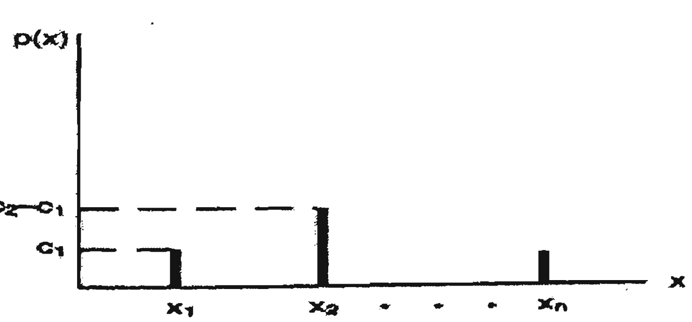


Figure 3.20. Empirical continuous piecewise-linear distribution function.

3.4.4.4. Empirical discrete distribution

The distribution returns only the data values themselves, using the probabilities to choose from among the individual values. The distribution parameter is defined by the set of n possible discrete values x_1, x_2, ..., x_n that can be returned by the function and the cumulative probabilities c_1, c_2, ..., c_n associated with these discrete values. Figure 3.21 illustrates the density function of empirical discrete distribution.



$$p(x_j) = c_j - c_{j-1}$$

where $c_0 = 0$

Figure 3.21. Empirical discrete ($c_1, x_1, c_2, x_2, \ldots$) distribution function.

The cumulative probability (c_j) for x_j is defined as the probability of obtaining a value that is $\leq x_j$. Hence c_j is equal to the sum of p_k for k from 1 to j, where p_k is the probability of obtaining the sample value x_k. By definition $c_n = 1$. Figure 3.22 gives an illustration of discrete empirical distribution function.

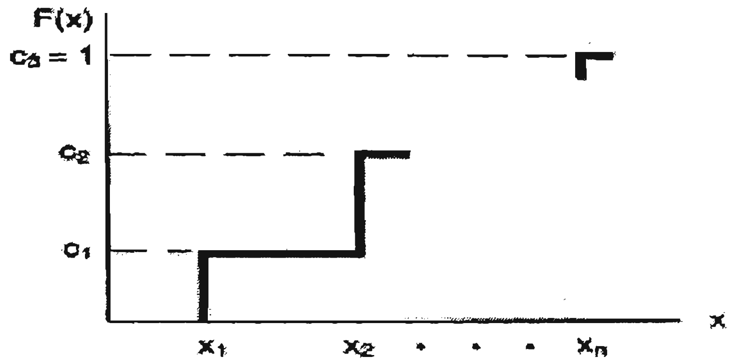


Figure 3.22. Discrete empirical distribution function.

3.5. Assessing the quality of the distribution's fit to the data

After selection of a specific distribution to represent the data it is essential to test the quality of the distribution's fit to the data. There are three measures of the quality of fit of a distribution to the data:

- Mean square error test,
- Chi-Square test, and
- Kolmogorov-Smirnov (K-S) test.

3.5.1. Mean square error criteria

The mean square error is the sum of $\{f_i - f(x_i)\}^2$, summed over all histogram intervals. In this expression f_i refers to the relative frequency of the data for the ith interval, and $f(x_i)$ refers to the relative frequency for the fitted probability distribution function over the cell's data range. This last value is obtained by integrating the probability density across the interval. If the cumulative distribution is known explicitly, then $f(x_i)$ is determined as $F_c(x_i) - F_c(x_{i-1})$, where F_c refers to the cumulative distribution, x_i is the right interval boundary and x_{i-1} is the left interval boundary. If the cumulative distribution is not known explicitly, then $f(x_i)$ is determined by numerical integration. However, this has been calculated by using the ARENA simulation software. The larger this mean square error value, the further away the distribution is from the actual data (see Appendix C and F).

The other two measures of the fit of a distribution to the data are the Chi-Square and K-S test. These are standard statistical hypothesis tests that can be used to determine whether a theoretical distribution is a good fit to the data.

3.5.2. Chi-Square Test

To compute the chi-square test statistic for either continuous or discrete distributions, we must first divide the entire range of the fitted distribution into k adjacent intervals $[a_0, a_1)$, $[a_1, a_2)$, $[a_{k-1}, a_k)$. The Chi-Square statistic is calculated as follows:

$$\chi^2 = \sum_{j=1}^{k} \frac{(f_j - f_e)^2}{f_e} \qquad [3.16]$$

where $\sum_{j=1}^{k}$ is sum over all k intervals, f_j is the observed frequency in the jth interval, and f_e is the expected frequency for each interval predicted by the theoretical distribution. The expected frequency is defined by np_j, where n is the number of observed data and p_j is the expected proportion of the x_i's (frequency) that will fall in the jth interval. In the continuous case,

$$p_j = \int_{a_{j-1}}^{a_j} \hat{f}(x)\,dx \qquad [3.17]$$

where $\hat{f}$ is the density of the fitted distribution.

For discrete data, $p_j = \sum_{a_{j-1} \le x_i < a_j} \hat{p}(x_i)$ [3.18] where $\hat{p}$ is the mass function of the fitted distribution. The frequency or count must be at least 5 (i.e. $np_j \geq 5$) in each class or interval. If we do not have an expected class size of 5, we must group adjacent classes together until we have the desired number.

If the calculated value of χ^2 is greater than the tabulated value at a given level of significance and appropriate degrees of freedom, then we reject the null hypothesis (H_0) that the data comes from the distribution of no difference, and conclude that the observed frequencies differ significantly from the expected frequencies at that level of significance. The critical values of χ^2 statistic are tabulated by degrees of freedom versus significance level (see Appendix B). The degrees of freedom, ν, used in the test is

$$\nu = k - 1 - p_p \qquad [3.19]$$

where p_p is the number of population parameters used in the calculation of the theoretical frequencies, which were estimated from the observed data. For example, if the estimated mean and standard deviation were used from the observed data to calculate the expected frequencies for a normal distribution, then p_p is 2 and the degrees of freedom are k-1-2.

Similarly, if the calculated value of χ^2 is less than the critical value of χ^2 at the significance level chosen and degrees of freedom, then we do not reject the null hypothesis (H_0) that there is no difference between what we observed and what we would expect to observe from a specified distributed variable.

The lack of a clear cut rule for interval selection is the major drawback of the chi-square test. In some situations entirely different conclusions can be reached from the same set of data depending on how the intervals are specified.

3.5.3. Kolmogorov-Smirnov (K-S) test

The K-S test compares an empirical distribution function with the distribution function of the hypothesized distribution. This test does not require grouping of a data set and is valid for any sample size. However, the range of applicability of K-S test is more limited than that for chi-square tests.

First, for discrete data sets, there are no critical values readily available and they must be computed using a complicated set of formulas [see Law and Kelton, 1991 and Conover (1980, pp. 350-352)]. Secondly, the K-S test is valid only if all the parameters of the hypothesized distribution are known and the distribution is continuous.

To define the K-S statistic, we must divide the distributions of both the observed data and the theoretical distributions into classes or intervals, and the absolute deviation between the two cumulative distributions for each class is calculated as follows:

$$D^{+} = \max\left\{\frac{i}{n} - G^{*}(x_i)\right\} \text{ for all values of } x. \qquad [3.20]$$

$$D^{-} = \max\left\{G^{*}(x_i) - \frac{(i-1)}{n}\right\} \text{ for all values of } x. \qquad [3.21]$$

where $G^{*}(x_i)$ is the theoretical cumulative distribution to which we fit the observations $\{x_i\}$.

The calculated K-S statistic, which is to be compared to the tabulated critical value, is the class deviation with the largest absolute value.

$$D = \max\left\{D^{+}, D^{-}\right\} \qquad [3.22]$$

If the critical value for a K-S test with degrees of freedom = N and α_n = 0.05 is greater than the K-S statistic, we do not reject the null hypothesis (H_0) of no difference between what we observed and what we would see from the fitted distribution. The degrees of freedom are equal to the sample size (n). If K-S statistic is greater than the critical value, we reject the null hypothesis (H_0) of no difference between the observed value and the fitted distribution. For $n \geq 35$ an approximation for the critical values of D is

$$D_{0.05} = \frac{1.36}{\sqrt{n}} \text{ at } \alpha_n = 0.05 \text{ level.} \qquad [3.23]$$

3.6. The use of *p*-values in hypothesis testing

One way to report the results of a hypothesis test is to state that the null hypothesis (H_0) was or was not rejected at a specified α_n-value or level of significance. The denial of the null hypothesis is the alternative hypothesis (H_1). The intent of hypothesis testing is to develop a decision rule for using the data to choose either H_0 or H_1. Two kinds of errors may be committed when testing hypotheses. If the null hypothesis is rejected when it is true, then a type I error has occurred. If the null hypothesis is not rejected when it is false, then a type II error has been made [Montgomery (1997, pp. 34-38)]. The probabilities of these two errors are given special symbols.

p (type I error) $= p$ (reject H_0/H_0 is true)
p (type II error) $= p$ (fail to reject H_0/H_0 is false)

If we reject H_0 we are making a fairly strong and confident decision that H_1 is true. But if we cannot mount enough evidence against H_0 to reject it, we have not necessarily proved that the null hypothesis (H_0) is the truth - we have just failed to find evidence against it. The reason for failing to reject H_0 could of course be that it is really true. But another reason for failing to reject null hypothesis (H_0) is that we just do not have enough data to see that H_0 is false. This approach may be unsatisfactory, so decision makers might be uncomfortable with the risks implied by $\alpha_n = 0.05$.

To avoid these difficulties, the p-value approach has been adopted widely in practice. The p-value is the probability that the test statistic will take on a value that is at least as extreme as the observed value of the statistic when the null hypothesis H_0 is true. Thus, a p-value conveys much more information about the weight of evidence against H_0, and so a decision maker can draw a conclusion at any specified level of significance. We define the p-value as the smallest level of significance that would lead to rejection of the null hypothesis H_0. The test statistic is significant when the null hypothesis H_0 is rejected;

therefore, we may think of the p-value as the smallest level α_n at which the data are significant. Once the p-value is known the modeller can determine how significant is the fit of distribution to the data. If the p-value is small (less than about 0.05), it is very hard to get information more in favour of H_1 than the information and indicate that distribution is not a very good fit. If the p-value is large (above 0.05), then it is possible that our data are more in favour of H_1 and indicate better fits. Of course, a high p-value does not constitute proof of a good fit – just a lack of evidence against the fit. Most simulation programs have an input analyser which report p-values.

3.7. Model building

In the process of building the simulation model, it is very important to select the correct choice of the simulation software. We faced one problem that no simulation model had been used before for the container terminal operations in the West Swanson Dock, Melbourne. Therefore the decision was made to use industrial simulation software for our particular purpose. Using industrial simulation software does not mean that we are ignoring the previous simulation models in the literature. There are more than 50 pieces of discrete-event simulation software reported in a survey (see Swain, 1997). The 1998 simulation Buyer's guide in IIE Solutions (Anon, 1998) showed 53 entries. The selection criteria of simulation software are provided in the literature (see Banks and Gibson, 1997, Robinson, 1994, and McHaney, 1991 for example).

ARENA, ProModel, and GPSS/H are among the top 50 simulation tools according to a survey conducted by Swain (1997). Some of the other tools might be better suited than any of these for particular modelling activities. The choice of these three is based on the belief that they are reasonably representative. In our case other simulation languages such as ProModel and GPSS are not available, which leaves ARENA as the most convenient software, because it was readily available in the University during the initial stage of this project. The model building processes using the ARENA simulation software are described in Appendix D and G. Figure 3.23 shows the schematic of the simulation process in the container terminal system.

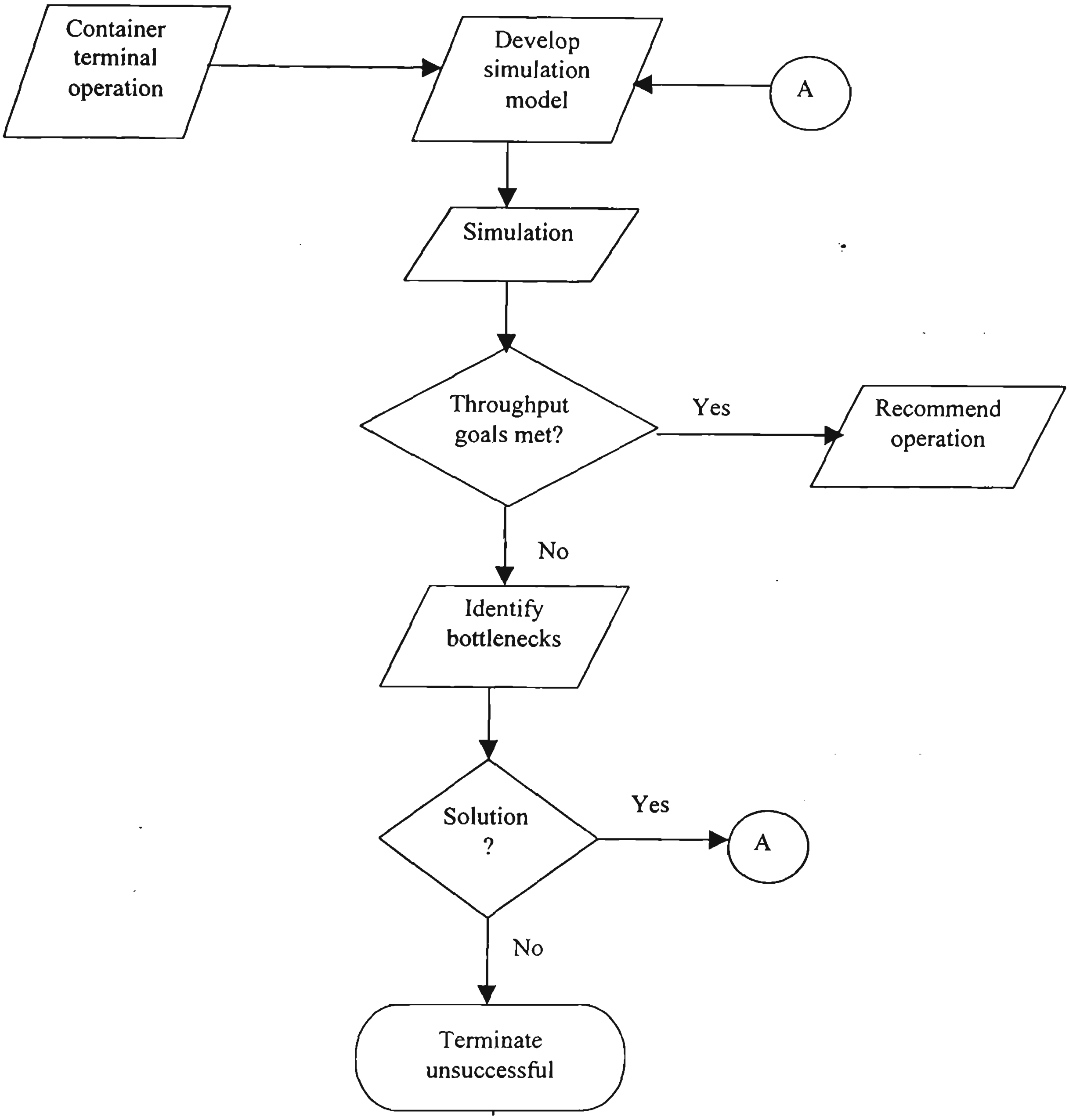


Figure 3.23. Schematic of the simulation model process in the container terminal.

3.7.1. Structure of ARENA simulation language

ARENA is a Windows-based simulation environment based on the SIMAN V simulation language (Pegden *et al.*, 1995, Kelton *et al.*, 1998 and Arena User's Guide version 3.5). SIMAN language refers to the objects that are the things in the system and the model that are the main concern of the analysis (Pegden *et al.*, 1995). The approach used in

ARENA is process-interaction or entity flow oriented. ARENA uses a directed block diagram consisting of several graphical simulation modelling - and analysis modules, each of which has a unique function to build a wide variety of simulation models. The entities flowing through the modules define system components.

We have already mentioned in previous sections that the ARENA input analyzer was used to specify the probability distribution from which observations are generated and drive the simulation with them. The details of this application will be discussed in the data analysis sections of chapters 4 and 5 and in Appendix D and G. After we have created a model in the ARENA environment, both model and experiment files are automated.

3.7.2. Parameter estimation

The statistics generated from the simulation output are a function of the random processes within the model and are therefore random variables. The estimation of a particular parameter from the observations generated by the simulation model is subject to error, because the observations randomly fluctuate within the model. A point estimate and interval estimates of the parameter are needed to account for these errors. A point estimate is a single value that estimates the parameter of interest but gives no indication of the magnitude of the possible error resulting from fluctuations in the underlying random process. The point estimate alone has no basis for interpreting the reliability.

The interval estimate also called a confidence interval provide a range of values around the point estimate that have a specified likelihood of containing the parameter's value. To qualify the further we can say that the true value is between lower and upper limits with a specified probably and provide a quantitative estimate of the possible error in the point estimate of the parameter. A large confidence interval indicates that the point estimate is not very good. The width of the interval is related to both variability of the system and the amount of data collected to form an estimate. A small confidence interval requires sufficient data. The actual analysis of the output directly depends on whether the simulation is of terminating or non-terminating nature.

3.7.3. Terminating or non-terminating simulations

The approach used to analyse the output results of a simulation depends on whether the system is terminating or non-terminating (Goldsman, 1992). A terminating system has a fixed starting condition and an event that defines the natural end of the simulation. In our case, the container terminal opens its services to road vehicles at a fixed time and closes at the end of the afternoon shift for container handling purposes. The container terminal operation is modelled as a terminating system. A non-terminating system has neither a fixed starting condition nor a natural ending point. In the West Swanson Dock seaside operation (loading and unloading of containers from or onto vessels) tend to be of the non-terminating type, because they do not have a fixed starting condition to which they return and loading and unloading operation from one day is typically carried over to the next day. However, the simulation of the seaside operation was beyond the scope of this research. The present study was confined to terminating simulations.

3.7.4. Analysing terminating or single system simulations

In a terminating system, the management of the terminal defines both the starting and terminating condition. The only decision in controlling the sample size is how many replications of the simulation to execute. The analysis deals with the individual observations within each replication. In this case, each replication produces a single observation hence the total number of observations is the number of replications of the model.

The next approach is control of the random-number of streams. It is assumed that observations are statistically independent. Independence implies that the outcome of one observation does not affect the outcome of any other observation. Although the observations within a given run typically are highly correlated, observations across replications are independent, because we use different random number seeds for each replication. In simulation analysis, observations within the replication have a normal distribution based on the central limit theorem.

3.7.5. Estimating confidence interval on the mean

The estimate of the confidence interval for the expected value of a model parameter determines whether we need additional replication. Reporting the value of model parameter based on less number of replications could be very misleading (Banks, 1996). To facilitate the analysis of the confidence interval, the following procedure was used:

Confidence interval on the mean in the form:

$$\text{mean} = \left[\overline{X} - h, \overline{X} + h\right] \tag{3.24}$$

where $\overline{X}$ is the point estimate of the mean, and h is called half-width of interval. If constructed properly, a random-sample mean $\overline{X}$ will fall within the interval with a probability of $1-\alpha_n$. This probability is called the confidence level of the interval. The half-width h is a measure of the precision of our point estimate, $\overline{X}$, of the true but unknown mean. The smaller the half-width, the better our estimate of the mean. The half-width is reduced by increasing the number of observations used to form $\overline{X}$

Let X_R denote the sample observation recorded on the Rth replication of a terminating system's simulation model. If there is a total of n_r independent replications of the model, then the mean $\overline{X}$, and variance S^2 of X and $\overline{X}$ from the K observations as follows

$$\overline{X} = \sum_{R=1}^{K} \frac{X_R}{K} \tag{3.25}$$

$$S^2(X) = \sum_{R=1}^{K} \frac{(X_R - \overline{X})^2}{K-1} \tag{3.26}$$

$$S^2(\overline{X}) = \frac{S^2(X)}{K} \tag{3.27}$$

If the X values are normally distributed, then a half-width, h gives an exact $1\text{-}\alpha_n$ confidence interval for the true mean, centered at $\overline{X}$. The half-width is computed as follows:

$$h = t_{K-1,1-\alpha_n/2}\ S(\overline{X}) \qquad [3.28]$$

where $t_{K-1,1-\alpha_n/2}$ is obtained from a table of t-values and is the upper $\alpha_n/2$ point of the student-t distribution with K-1 degrees of freedom. The confidence interval for the mean is graphically presented in Figure 3.24.

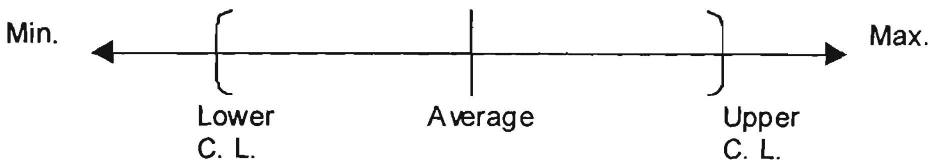


Figure 3.24. Confidence interval showing lower limit and upper limit about mean to determine the number of replications.

The main disadvantage of this approach is that we have no control over the resulting half-width. In some instances more replications are necessary to achieve a desired half-width. To obtain the desired half-width the following relationship can be employed:

$$n_r^* = n_r\,(h/h^*)^2 \qquad [3.29]$$

where n_r^* is the total number of replications required and can be rounded up to a next integer, n_r is the number of replications in the pilot run, h is the half-width of the confidence interval for the pilot run, and h^* is a desired half-width. We can see from this equation that an increase in the number of replications is inversely proportional to the square of the fractional decrease in the confidence interval width. After computing n_r^*, we then make $n_r^* - n_r$ additional replications of the model ensuring that the starting seed for the second set of independent replications differs from the starting seed of the first set of replications.

3.7.6. Controlling of randomness in simulation result

To analyse the output from a simulation, we must control the model's random inputs. ARENA has a SEEDS element, which can control the random processes. By default, ARENA has ten random number streams referenced as stream numbers one to ten. The SEEDS element can be used to control the default streams or to define an arbitrary name or number stream. How random samples are generated in simulation is given in many texts for example Hoover and Perry [1990], Law and Kelton [1991], Pegden, *et al.* [1995], and Kelton [1996]. To obtain *n* independent replications of the model is to make a single run of *n* replications without changing default seeds. However, if additional replications are required for two stage statistical procedures we must use the SEEDS element to avoid a repeat of random values. In our case we have used 30 independent replications and analysis of the confidence intervals on the means shows that we do not require additional replications in second stage of simulation. Therefore, we have not changed the default seeds for control of random values during the entire simulation project.

Simulations can be run with less replications by using variance reduction techniques. These techniques are discussed in texts by Law and Kelton [1991] and Pegden *et al.* [1995] for reduction of variance in the point estimate for the mean response. We have not used this technique in simulation models, because there is no way to know in advance whether this will reduce the variance.

3.8. Model verification and validation

A number of methods is discussed in the literature for verification and validation of simulations [see for example (Shannon 1981, Sargent 1982, 1984, 1996, Hoover and Perry 1990, Kleindorfer and Ganeshan 1993, and Pegden *et al.* 1995)]. There are 15 principles established in model verification and validation by Balci [1995]. Model verification can be seen as a micro check of simulation. The model must be checked during the model building processes and each element must be tested individually. Test runs are used to reveal errors of logic in the model. The next step of verification is tracing the model's operation. ARENA has a trace feature that examines in detail the movement of entities through the system. The trace consists of a detailed history of all entity movements through the block diagram. It is not possible to trace the entire simulation in large models, because the output would be too large. We followed the trace by specifying starting time and ending time. Verification can also performed by checking the parameters of the selected probability distribution. Care should be taken to avoid errors in units of measurement. Blockages and deadlocks sometimes trigger queues of unusual length in models. This can be checked by animation and trace. Sometimes model errors occur due to overwriting variables, attributes, arithmetic errors, and data recording errors in the model.

A model is only valid for the purpose for which it is built and can be seen as a macro checking of the simulation. Robinson (1994) provides the difference between verification and validation, which are summarised in Table 3.1.

Table 3.1. Model verification and validation.

Verification	Validation
Micro level checking	Macro level checking
Performed during model building	Performed on completion of model building
Test each element individually	Test model accuracy to meet the project's objectives

The model validation process is grouped into two specific types:

- Face validity
- Comparison with the real system

Face validity

Two methods for obtaining face validity are to observe the model run for a period of time and demonstrating the model to management. We have watched the animation of simulation to see whether the model is building large queues or not releasing the resource when the entity is waiting to seize the resource. Demonstrating the model to the operations staff of the terminal was very useful for obtaining feedback regarding the accuracy of the model and its ability to meet the project's objectives.

Comparison with the real system

Performance of the model can be compared with the real system. The data should be collected from the real system can be compared to the results of the simulation. This is the method we have employed in our studies.

3.9. Model experimentation

Discrete-event simulation is the primary analysis tool for designing complex systems. However, simulation must be linked with mathematical modelling techniques to improve the analysis for examining the sensitivity of the simulation output to parameters of the simulation and understanding the decision making processes. There are several mathematical models available for representing the simulation model's input and output functions. These are described by Barton (1992), including:

- Taguchi models
- Generalised linear models
- Methods based on splines
- Radial basis functions
- Kernel smoothing
- Spatial correlation models
- Frequency domain approximations

Of the above models, Barton (1992) suggests that generalised linear models based on parametric polynomial response surface approximations are most commonly used, because the techniques of experimental design, computation, interpretation and assessment are well defined in this approach. However, for other models there are no methodologies well defined for computation, they are computationally intensive and they are more difficult to interpret.

Farrington and Swain (1993) have also suggested that the response surface technique is useful for representing the relationship between the inputs and outputs, design of experiments and the assessment of the adequacy of the fitted model. The experimental design of the simulation model is the basis for developing the mathematical expressions for simulation's input and output variables.

A wide set of system designs can be examined by changing the values of variables in the base model. Factorial and fractional factorial designs are often used. We can evaluate the system designs by using the either factorial design or fractional factorial design. The input parameters of a base model are called factors and the output performance measures are called responses.

3.9.1. Factorial design

For experiments where each of the factors has the same number of levels the number of experiments can be calculated as follows:

Number of experiments = number of levels$^{\text{number of experimental factors}}$

For example, if there are three factors and each are at two levels; a complete replicate of such a design requires 2^3, that is 8, experiments. This means that the choice of experiments needs to be considered carefully in order to save simulation completion time. This will be discussed in chapter 5. In a 2^r factorial design, it is easy to express the results of the experiments by response surface methods. Although factorial designs are more efficient, they may also be time consuming if the number of input variables becomes large. Fractional factorial designs overcome some of these problems, Box *et al.* (1978) describes these design methods. However, their application becomes complex especially when the number of input variables increases (Madu and Kuei, 1993).

3.9.2. Fractional factorial designs

In many cases, the 2^r factorial design may not be useful where a large number of experiments needs to be performed and project time scales may prevent a full evaluation of all alternatives. As a result, fractional factorial design can be used in order to cut down the number of experiments while still preserving the basic factorial designs. In general, we denote a half (either positive or negative) fraction of the 2^r by $\frac{1}{2}2^r = 2^{r-1}$, where 2 indicates the number of levels for each factor, the exponent r indicates the number of factors, and the exponent -1 indicates a half fraction (2^{-1}).

3.9.3. Response surface methods

Response surfaces consist of a group of techniques used in the empirical study of relationships between measured responses and input variables. The main object of this method is to show how a particular response y affected by a given set of input variables x_u over some specified region of interest. The basic underlying relationship between the input variables and response variables can be investigated by polynomial approximations. A general polynomial can be written

$$\begin{aligned} y = {} & \omega_0 + (\omega_1 x_{u1} + \omega_2 x_{u2} + \ldots + \omega_g x_{ug}) + (\omega_{11} x_{u1}^2 + \omega_{22} x_{u2}^2 + \ldots + \omega_{gg} x_{ug}^2 \\ & + \omega_{12} x_{u1} x_{u2} + \omega_{13} x_{u1} x_{u3} + \ldots + \omega_{g-1,g} x_{ug-1} x_{ug}) + (\omega_{111} x_{u1}^3 + \omega_{222} x_{u2}^3 \\ & + \ldots + \omega_{kkk} x_{ug}^3 + \omega_{112} x_{u1}^2 x_{u2} + \omega_{122} x_{u1} x_{u2}^2 + \ldots + \omega_{g-1,g,g} x_{ug+1}^2 x_{u\,g-1}) \\ & + (\omega_{1111} x_{u1}^4 \ldots) + \text{etc.} + \varepsilon, \end{aligned} \qquad [3.30]$$

where ω 's are coefficients or (empirical) parameters and ε is a random error. The number of coefficients or parameters increases rapidly as the number of the input variables, u, and the order or degree, d, of the polynomial are both increased (Box and Draper, 1987). Table 3.2 shows the number of coefficients in polynomials of order, d, involving u inputs.

Table 3.2. Relationship of coefficients between order d and inputs u in polynomial approximations.

Number of inputs, u	Order or degree of polynomials, d			
	Linear	Quadratic	Cubic	Quartic
2	3	6	10	15
3	4	10	20	35
4	5	15	35	70
5	6	21	56	126

The higher the order of the approximation function, the more closely a Taylor series can approximate the true function. Many real world problems require pure quadratic terms, such as x_{uj}^2, and such as $x_{uj}x_{ug}$ in the prediction equation, in order to represent the curvature in the system and therefore a linear model may not be adequate. In this case we have used second-order quadratic terms. For example, the second-order polynomial approximation for $u = 2$ predictor or design variables, X_{u1}, and X_{u2}, can be defined as

$$y = \omega_0 + \omega_1 x_{u1} + \omega_2 x_{u2} + \omega_{11} x_{u1}^2 + \omega_{22} x_{u2}^2 + \omega_{12} x_{u1} x_{u2} + \varepsilon \qquad [3.31]$$

where ω's are coefficients associated with design variables, y is the response variable, and ε is random error. This is also called a second-order multiple regression model with two independent variables. We see that the interaction really involves the product of the design variables associated with the two factors. We can see another example of the second-order polynomial approximation for $u = 3$ predictor or design (input) variables, X_{u1}, X_{u2}, and X_{u3}, defined as

$$\begin{aligned} y = {} & \omega_0 + \omega_1 x_{u1} + \omega_2 x_{u2} + \omega_3 x_{u3} + \omega_{11} x_{u1}^2 + \omega_{22} x_{u2}^2 \\ & + \omega_{33} x_{u3}^2 + \omega_{12} x_{u1} x_{u2} + \omega_{13} x_{u1} x_{u3} + \omega_{23} x_{u2} x_{u3} + \varepsilon \end{aligned} \qquad [3.32]$$

In the Equation 3.30, input variables X_{u1}, X_{u2}, X_{u3}, . . . , X_{ug} are more conveniently used in the coded forms. In the simulation experiment input variable ranges between a lowest value and an upper value. Measure the variation or spread of input variable by the semirange and its location by the mean. Then, the relationship between the input variables and the coded variables is

$$x_{u1} = \frac{X_{u1} - (X_{u1\,\text{low}} + X_{u1\,\text{high}})/2}{(X_{u1\,\text{high}} - X_{u1\,\text{low}})/2}, \qquad [3.33]$$

$$x_{u2} = \frac{X_{u2} - (X_{u2\,\text{low}} + X_{u2\,\text{high}})/2}{(X_{u2\,\text{high}} - X_{u2\,\text{low}})/2}, \text{ and} \qquad [3.34]$$

$$x_{ug} = \frac{X_{ug} - (X_{ug\,\text{low}} + X_{ug\,\text{high}})/2}{(X_{ug\,\text{high}} - X_{ug\,\text{low}})/2} \qquad [3.35]$$

When the input variables have only two levels, we can name one the "low" or -1 level and other the "high" or $+1$ level. This coding will produce the familiar ± 1 notation for the levels of the coded variables. For example, if the design contains $2^3 = 8$ distinct treatment combinations, then ± 1 notation for the levels of the coded variables will be

x_{u1}	x_{u2}	x_{u3}
-1	-1	-1
1	-1	-1
-1	1	-1
1	1	-1
-1	-1	1
1	-1	1
-1	1	1
1	1	1

The method of estimating the second order regression coefficients by using the least squares parameter estimates is discussed in the following section.

The method of least squares is typically used to estimate the coefficients in a polynomial approximation or regression model. The use of matrices in the least square estimate is useful to solve any regression model no matter how many terms there are in the regression equation. Suppose that $l > g$ observations on the response variable are available, say $y_1, y_2, \ldots\ldots, y_l$. Along with each observed response y_i, we will have an observation on each predictor or design variable and let x_{uij} denote the ith observation or level of variable x_{uj}. The data will appear as in Table 3.3.

Table 3.3. Data for multiple regression model.

y	x_{u1}	x_{u2}	$\cdots$	x_{ug}
y_1	x_{u11}	x_{u12}	$\cdots$	x_{u1g}
y_2	x_{u21}	x_{u22}	$\cdots$	x_{u2g}
.	.	.	$\cdots$	.
.	.	.	$\cdots$	.
.	.	.	$\cdots$	.
.	.	.	$\cdots$	.
y_l	x_{ul1}	x_{ul2}	$\cdots$	x_{ulg}

We may write the model equation in terms of the observations in Table 3.3 as

$$y_i = \omega_0 + \omega_1 x_{ui1} + \omega_2 x_{ui2} + \ldots + \omega_1 x_{uig} + \omega_{11} x_{ui1}^2 + \omega_{22} x_{ui2}^2 + \ldots + \omega_{gg} x_{uig}^2$$
$$+ \omega_{12} x_{ui1} x_{ui2} + \omega_{13} x_{ui1} x_{ui3} + \ldots + \omega_{g-1,g} x_{ui,g-1} x_{uig} + \varepsilon_i$$

$$y_i = \omega_0 + \sum_{j=1}^{g} \omega_j x_{uij} + \sum_{j=1}^{g} \omega_{jj} x_{uij}^2 + \sum_{j=1}^{g} \sum_{j'=1}^{g} \omega_{jj'} x_{uij} x_{uij'} + \varepsilon_i, \qquad [3.36]$$

where i=1, 2, 3, ... , l. The model in terms of the observations in Equation 3.36, may be written in matrix notation as

$$y = X\omega + \varepsilon \qquad [3.37]$$

where $y = \begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_l \end{bmatrix}$,

$$X = \begin{bmatrix} 1 & x_{u11} & x_{u12} & x_{u13} & \cdots & x_{u1g} & x_{u11}^2 & x_{u12}^2 & x_{u13}^2 & \cdots & x_{u1g}^2 & x_{u11}x_{u12} & x_{u11}x_{u13} & x_{u12}x_{u13} & \cdots & x_{u1g}x_{u1,g-1} \\ 1 & x_{u21} & x_{u22} & x_{u23} & \cdots & x_{u2k} & x_{u21}^2 & x_{u22}^2 & x_{u23}^2 & \cdots & x_{u2g}^2 & x_{u21}x_{u22} & x_{u21}x_{u23} & x_{u22}x_{u23} & \cdots & x_{u2g}x_{u2,g-1} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & & \cdot \\ 1 & x_{ul1} & x_{ul2} & x_{ul3} & \cdots & x_{ulg} & x_{ul1}^2 & x_{ul2}^2 & x_{ul3}^2 & \cdots & x_{ulg}^2 & x_{ul1}x_{ul2} & x_{ul1}x_{ul3} & x_{ul2}x_{ul3} & \cdots & x_{ulg}x_{ul,g-1} \end{bmatrix},$$

$\beta = \begin{bmatrix} \omega_0 \\ \omega_1 \\ \cdot \\ \cdot \\ \cdot \\ \omega_{g,g+1} \end{bmatrix}$, and $\varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdot \\ \cdot \\ \cdot \\ \varepsilon_l \end{bmatrix}$

In general, y is an $(l \times 1)$ vector of the observations, X is an $(l \times q)$ matrix of the levels of the independent variables, ω is a $(q \times 1)$ vector of the regression coefficients, and ε is an

$(l \times 1)$ vector of random errors. We wish to find the vector of least squares estimators, $\hat{\omega}$, so that the sum of the squares of the errors, ε_i, is minimized. The least squares function is

$$\sum_{i=1}^{l} \varepsilon_i^{\,2} = \sum_{i=1}^{l} \left(y_i - \omega_0 - \sum_{i=1}^{g} \omega_i x_{ui} - \sum_{i=1}^{g} \omega_{ii} x_{ui}^2 - \sum_{i=1}^{g} \sum_{j \geq i}^{g} \omega_{ij} x_{ui} x_{uj} \right)^2, \text{ or} \qquad [3.38]$$

$$L = \sum_{i=1}^{l} \varepsilon_i^2 = \varepsilon'\varepsilon = (y - X\omega)'(y - X\omega)$$

Note that L may be expressed as

$$L = y'y - \omega' X' y - y' X\omega + \omega' X' X\omega = y'y - 2\omega' X' y + \omega' X' X\omega \qquad [3.39]$$

since $\omega' X' y$ is a (1×1) matrix, or a scalar, and its transpose $(\omega' X' y)' = y' X\omega$ is the same scalar. The least squares estimators must satisfy

$\left.\dfrac{\partial L}{\partial \omega}\right|_{\hat{\omega}} = -2X'y + 2X'X\hat{\omega} = 0$ which simplifies to

$$X'X\hat{\omega} = X'y \qquad [3.40]$$

Equation 3.40 is the matrix form of the least squares normal equations. The least squares estimator of ω from the normal equations is

$$\hat{\omega} = (X'X)^{-1} X'y \qquad [3.41]$$

where $X'X$ is a $(q \times q)$ symmetric matrix and $X'y$ is a $(q \times 1)$ column vector. The diagonal elements of the $X'X$ are the sums of the elements in the columns of X, and the off-diagonal elements are the sums of the cross products of the elements in the columns of X. Similarly, the elements of $X'y$ are the sums of cross-products of the columns of X and the observations $\{y_i\}$. The fitted second-order model is

$$\hat{y} = X\hat{\omega} \qquad [3.42]$$

The difference between the actual observation y_i and the corresponding fitted value $\hat{y}_i$ is called the residual. However, solving the Equation 3.41 for coefficients are not easy manually. These computations are almost always performed with statistical software. In our case we have used S-Plus software (S+Dox^{TM} User's Manual, 1997).

From the fitted Equation 3.42 we can have a plot of contour lines of y-values generated by the various combinations of x_{u1} and x_{u2} or, x_{u1}, x_{u2} and x_{u3} plane.

3.9.4. Test for significance of model

The test for significance of second-order model is a test to determine if there is quadratic relationship between the response variable y and a subset of the predictor or designed variables $x_{u1}, x_{u2} \ldots, x_{ug}$. The hypotheses for testing the significance of any individual coefficient (i.e. say ω_j) in the model are

$$H_0 : \omega_j = 0 \text{ and } H_1 : \omega_j \neq 0. \qquad [3.43]$$

Such a test is useful in determining the value of the each of the predictor or designed variables in the regression model. For example the model might be more effective with the inclusion of additional variables or deletion of one or more variables already in the model. The test statistic for this hypothesis is

$$t_0 = \frac{\hat{\omega}_j}{\sqrt{\hat{\sigma}^2 C_{jj}}} \qquad [3.44]$$

where $\hat{\sigma}^2 = \frac{SS_E}{l-q} = \frac{y'y - \hat{\omega}'X'y}{l-q}$, $q = u+1$, and C_{jj} is the diagonal element of $(X'X)^{-1}$ corresponding to $\hat{\omega}_j$. The null hypothesis $H_0 : \omega_j = 0$ is rejected if $|t_0| > t_{\alpha_n/2, l-u-1}$. This is a partial test, because the coefficients depend on all the predictor variables in the model.

The standard error (standard deviation) of each regression coefficient is given by the square root of the corresponding element of the diagonal of the covariance matrix. The denominator of Equation 3.44 is called the standard error. Appendix E and H gives the least square estimate of each parameter, the standard error, the t statistic, and the corresponding p-value.

When the second order model is fitted to data, its adequacy can be tested by the F-test. The appropriate hypotheses are provided in Equation 3.43. The rejection of H_0 in Equation 3.43 implies that at least one of the predictor variables $x_{u1}, x_{u2}, \ldots, x_{ug}$ contributes significantly to the model. If the F value is small to the point that H_0 can not be rejected, we would have serious doubts about our model. If the F value is large, we are at least assured that the model is feasible. Of course, it does not mean that this particular model is in any way optimal. The F-statistic is basically a comparison of two variances. The test procedure for H_0 is to compute

$$F\text{-statistic} = \frac{SS_R/u}{SS_E/(l-u-1)} = \frac{MS_R}{MS_E} \qquad [3.45]$$

and to reject H_0 if F_0 exceeds $F_{\alpha_n, u, l-u-1}$. In the Equation 3.45 the SS_R is the sum of squares of the deviations of the predicted value of the ith observation from the mean or most often called sum of squares due to regression. Therefore, the regression sum of squares is

$$SS_R = \hat{\omega}'X'y - \frac{\left(\sum_{i=1}^{l} y_i\right)^2}{l}. \qquad [3.46]$$

In the same equation, SS_E is the sum of squares of the deviation of the ith observation from its fitted value or most often called sum of squares of the residuals or about the regression. The error sum of squares is

$$SS_E = y'y - \hat{\omega}'X'y \qquad [3.47]$$

The use of R^2 in the model is to generally measure the percentages of the variation in the dependent variable y explained jointly by the independent variables $x_{u1}, x_{u2}, \ldots, x_{ug}$ in the model. It is mostly reported in the output analysis of regression model as the coefficient of multiple determination or multiple R-squared. The R-squared value is defined as

$$\frac{SS_R}{SS_T} \qquad [3.48]$$

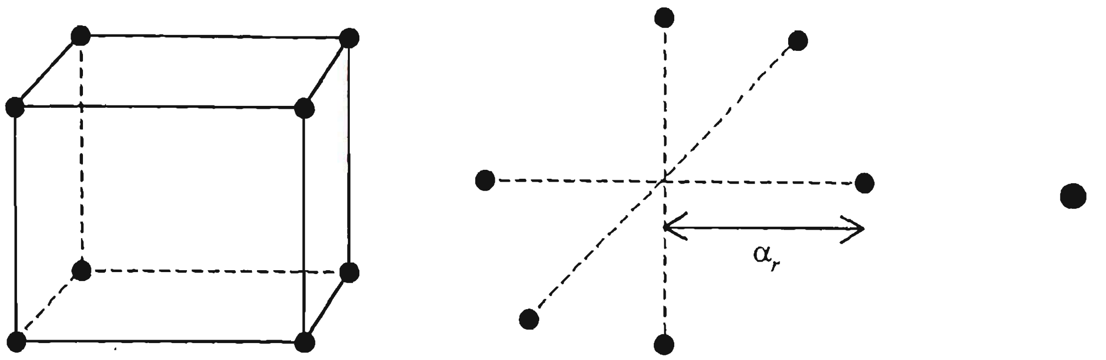
where SS_T is the sum of squares of deviations of the ith observations from the mean and is shortened to SS about the mean. The total sum of square (SS_T) is

$$SS_T = y'y - \frac{\left(\sum_{i=1}^{l} y_i\right)^2}{l} \qquad [3.49]$$

3.9.5. Central composite design

The central composite design consists of a two-level factorial or fractional factorial augmented with further points which allow pure quadratic effects in the model. In general, a central composite design consists of three portions [see Box and Draper (pp. 305-322, 1987), Tew (1992), Montgomery (pp. 601-605, 1997), and Vining (pp. 405-417, 1998)]:

- A 2^r full factorial or a fraction factorial runs with coordinates ($\pm 1, \pm 1, \ldots, \pm 1$) forming the cube portion of the design.
- $2r$ axial runs with coordinates ($\pm \alpha_r, 0, \ldots, 0$) ($0, \pm \alpha_r, \ldots, 0$), ... , ($0, 0, \ldots, \pm \alpha_r$) forming the star portion of the design at distance α_r from origin.
- Usually, at least one centre point at ($0, 0, \ldots, 0$).



Cube portion

$(x_{u1}, x_{u2}, x_{u3}) = (\pm, \pm, \pm)$

Star portion

$(x_{u1}, x_{u2}, x_{u3}) = (\pm\alpha_r, 0, 0),$
$(0, \pm\alpha_r, 0),$
$(0, 0, \pm\alpha_r)$

Centre portion

$(x_{u1}, x_{u2}, x_{u3}) = (0, 0, 0)$

Figure 3.25. A central composite design in three-factors showing cube, star and central portion.

A three factor central composite design is illustrated in Figure 3.25. A central composite design is made rotable by the choice of α_r. This means that the variance of the predicted response is the same at all points x_u that are the same distance from the design centre. That is, the variance of the predicted response is constant on spheres. A design with this property will leave the variance of $\hat{y}$ unchanged when the design is rotated about the centre (0, 0, . . . , 0). The specific choice of α_r depends on the experimentor. There are three choices:

- $\alpha_r = (n_f)^{\frac{1}{4}}$ yields a rotable central composite design, where n_f is the number of points used in the factorial portion of the design.
- $\alpha_r = \sqrt{r}$ creating a spherical central composite design and puts all the factorial and axial design points on the surface of a sphere of radius $\sqrt{r}$.
- 1, creating a face-centered cube in the central composite design. Generally three to five centre runs are recommended (Montgomery, 1997).

3.9.6. Transformation of variables

The choice of transformation is important when the observations for an output (response) variable y are vary considerably. The logarithmic transformation is one of the most widely used transformations in regression models. Working with the data on a log scale often has the effect of dampening variability and reducing asymmetry. Instead of fitting the model given in Equation 3.36 we now fit the model

$$\ln y_i = \omega_0 + \sum_{i=1}^{g} \omega_i x_{uig} + \sum_{i=1}^{g} \beta_{ii} x_{uig}^2 + \sum_{i=1}^{g} \sum_{j=1}^{g} \omega_{ij} x_{ui} x_{uj} + \varepsilon_i \qquad [3.50]$$

Sometimes, if the response variable to be fitted is nonlinear, then a transformation is chosen to make the response function linear. Many types of response data occur as proportions, $0 \le y_i \le 1$. The popular transformation for such data is the following.

$$\hat{y}_i = \ln \frac{y_i}{1 - y_i} \qquad [3.51]$$

The relationship is called the logistic response function and y is the natural logarithm of the ratio $y_i / 1 - y_i$. If y_i is in percentage term, then we can use the transformation

$$\hat{y}_i = \ln \frac{y_i \%}{100 - y_i \%} \qquad [3.52]$$

3.10. Conclusions

Despite significant academic research work in the field of simulation, there is a serious lack of awareness in modern container handling that an important issue facing the management is really a complex logistics process. This chapter presents a simulation methodology for improving logistics processes in marine container terminals. Empirical model building for investigation of different relationships between variables during the post process of simulation have been discussed for the efficient understanding of the variable or parameter affecting the logistics process. This chapter provides the basis for the actual application of simulation in chapter 4 and 5. The next chapter will discuss the simulation modelling of road vehicles in the gate system of a container terminal.

CHAPTER 4

SIMULATION MODELLING OF THE HANDLING OF ROAD VEHICLES

4.1. Introduction

Inefficient road vehicle (road trucks) procedures at the interface between the terminal and the inland road system reduce terminal efficiency because they affect vessel and yard operation (BTE, 1985). The gate operation in the terminal deals with both incoming and out going road vehicles. If the road vehicles' turnaround times are more at times of demand, that is not only unacceptable, but reflects badly on the image of the of the terminal operator and the transport carriers. Road vehicles spend most of the time in the terminal carrying out tasks associated with documentation and on grids. Since the documentation (paper work) gates and the grids are the primary road vehicle interface, it is essential to achieve a level of service equal to the expectation of road carriers. Because the paperwork at the gates is presently labour intensive and labour costs increase with the level of service, the longer the turnaround times of road vehicles the higher the cost of the transaction. The main challenges to improving service are the irregular arrival pattern of vehicles, variations in the documentation, and variations in loading and unloading times of road vehicles in the terminal.

Studies by Barr (1993) suggest that the terminal management has to re-examine the existing facilities with due regard to operational procedures before taking any decision on investment in equipment and manpower for seeking to improve efficiency in the handling of road vehicles.

There is a significant amount of published literature devoted to different aspects of container terminal simulation. Hayuth *et al.* (1994) have reviewed container terminal simulation models reported in the literature and they found simulation models differ widely in their objectives, complexity, detail, and the number of factors taken into consideration. This simulation study started by reviewing publications in the area of road vehicles' operation in container terminals. However, very few works on gate operation simulation models have been published to date. Some of the previous work is discussed below.

Koh *et al.* (1994) have developed a simulation model to mimic the main operations of the container port in Singapore which includes gate operation. But, their model mainly focussed on vessel turnaround times and yard block congestion and eventually there is no discussion on road vehicle operations. A other generic gate simulation model such as GENTRY was used for the development of Deltaport Container Terminal, Vancouver, British Columbia to analyse truck operations (Ward, 1995). The study focused on how many processing lanes, how much queue space, and how many workers are required to prevent truck queues from overflowing onto public roads. The model uses gate layout, truck arrival patterns, truck processing times, and worker schedules, and generates queue lengths, overall cycle times, and worker utilisation. However, this model was only used as a conceptual planning model. The data used to drive the model were collected from another existing terminal of Vancouver Port Corporation. There was no detailed discussion about the data analysis, validation and experimentation using the models.

A study by Hutchins and Akalin (1995) indicates that there are two simulation models developed by the Cargo Handling Program, a joint venture of US Flag Carriers and the Maritime Administration, which can be used for road vehicle operations in the container terminal. The first model, PCTERM (PC-based terminal equipment and resource model) is a planning version and the second model, TOSP (Terminal Operations Simulation Program) was developed for evaluation of existing operation of marine container terminals. However, the second model, TOSP is typically limited to a single shift operation or a day operation. Similarly, the PCTERM model is limited to longer-term operation of two weeks. They are confined to the discussion of these models but are no discussions in the context of actual applications.

Holguín-Veras and Walton (1996a) have developed the simulation model PRIOR (a FORTRAN based general model) for the performance analysis of port operations that includes gate operation of the terminal. They have calibrated the model using two approaches: combined models and empirical distributions. In the combined approach the authors have expressed service time as a function of a task's characteristics (e.g. distance travelled, type of container) and random components (usually statistical distributions). This approach was used for yard crane operations. In the other approach empirical distributions were used in those cases in which the characteristics of the service processes were not suitable for analytical modelling. This approach was used in yard gate operation. However, Holguín-Veras and Walton's (1996a) use of empirical distributions in the operation of gates is not fully explained by them.

Merkuryer *et al.* (1998) have discussed the key issues of the application of modelling and simulation in transport chains for management of the Riga Harbour Container Terminal, Latvia. This study was aimed at decreasing the amount of time that trucks remained at the terminal, bringing containers to the terminal, and/or taking them away. They have employed a triangular distribution for each service operation (e.g. entrance checkpoint, document processing point, customs, issuing import containers, container examination, receiving export containers and tallmen) of trucks. The servicing of 100 trucks during one working day is simulated. The triangular distribution for service time used by them may not be appropriate for a busy container terminal, and in any case the service time does not follow any standard probability distribution.

None of the above models has been described in detail. In addition the operation of road vehicles of each terminal is significantly different and the experience viewed in the process of development and experimentation of simulation may not be exactly applicable to other terminals. Models described in the literature do not exploit the advantages of regression-based techniques (response surface techniques) although such methods have been used to understand and explore simulation models for over 20 years (Blanning, 1975).

This chapter focuses on the movement of road trucks as they enter the West Swanson container terminal, and as they are loaded or unloaded. The magnitude of the operation is indicated by Figure 4.1, which shows that the terminal handles about 18,000 trucks per month.

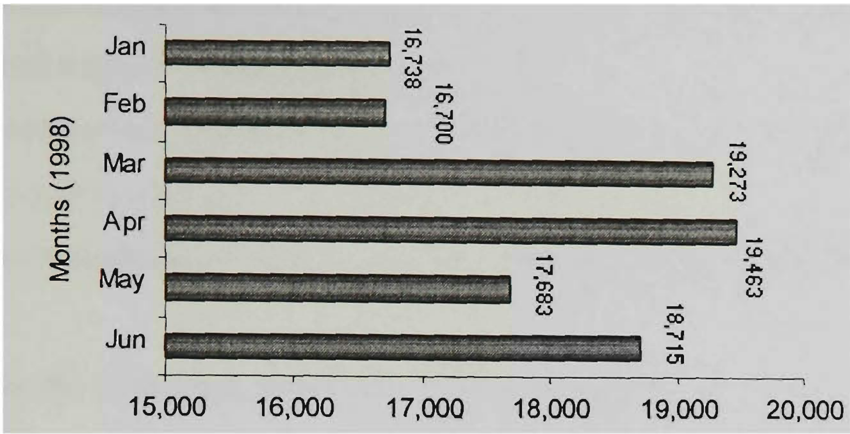


Figure 4.1. Trucks handled in the gate system of West Swanson container terminal.

4.2. General understanding of gate system

The trucks' access to the terminal is by pre-booked time slots through the P&O Ports vehicle booking system (VBS). Before arrival at the terminal, all trucks irrespective of whether they are export or import, have to book their time slot at least 24 hours in advance. All the consignees are required to book the time slot by their respective computers connected to the mainframe computer at the terminal. If any consignee does not have access to the mainframe of terminal it can booked by facsimile or phone call.

4.2.1. Time slot booking

A time slot is the 'time window' allocated to a truck before arrival to a terminal for guaranteed service by the management. Booking of time slots can be either by the VBS or by joining a standby queue. The advantages and disadvantages of VBS are:

Advantages

- Booking required by all trucks.
- Right to access to the terminal during the booked time.
- Guaranteed service by the management in the terminal

Disadvantages

- Late arrival will invite imposition of penalties by the management.
- Cancellations of time slots are not possible but trucks may exchange time slots with other trucks.

- Management will not accept any liability for trucks delays at the terminal.
- Late arrival trucks will join the standby queue.
- An import time slot cannot be changed to an export time slot, or used for an export container and vice versa.
- Registration is necessary with the management for all trucks under this category.

Following are the advantages and disadvantages of standby are:

Advantages

- All trucks are required to joining the standby queue specified outside the terminal gate.
- No pre-booking is required.
- No late arrival penalty is imposed.

Disadvantages

- There will be delays and access is not guaranteed at any time.
- Trucks' access to the terminal depends upon the progress within the system.
- No registration is required under this system with the management.

The VBS is only available to bonafide trucks, which are defined as those belonging to companies that directly manage and operate trucks carrying containers to and from the terminal. All trucks under VBS are registered to the VBS with a unique access code and utilise their own computer to book their time slots directly.

Each day (07.00am to 2.30pm day shift, 2.30pm to 10.00pm evening shift) is split into 14 time slot zones. The vessel receival cut off times and availability dates for imports are logged into the VBS computer by the operation department of the organisation prior to the vessel's arrival, thereby enabling time slots to be booked for that vessel. Bookings cannot be made for any vessel, import or export, prior to the advertised availability or receival dates.

When booking time slots, trucks are to enter the vessel's name, which will automatically identify the storage yard, and select either an import or export time slot. It is also necessary to provide information on whether the container is reefer, general, empty or hazardous and if its length is 20ft or 40ft along with the container's number. The truck may alter the vessel; container type, length or number of containers prior to the arrival at the terminal provided the container to be delivered or picked up is for the same storage yard as the time slot booked. However, an import time slot cannot be changed to an export time slot or used for an export container and vice versa. The exception to the above flexibility is that a truck booked for an import reefer time slot cannot change the container number or change the container type, nor can any import general, empty or hazardous time slot be changed to an import reefer time slot. The truck when booking an import reefer time slot must enter the container number as booked or the carrier will not be admitted and a penalty will be imposed.

4.2.2. Service strategy and service discipline of trucks at the terminal-a description of the system

An overview of the terminal gate system is shown in Figures 4.2 (a) and 4.2 (b). All the trucks whether export or import, before entering into the terminal, bifurcate into two separate queues called north bound and south bound park queues. All the trucks for northbound enter into the terminal through gate E located on the north side of the terminal. Similarly, trucks for the southbound park enter through gate D located on the same side of the terminal as indicated in Figure 4.2 (a). Upon arrival at the entry gates, the trucks move forward beyond the entry sign when called to do so by the transport supervisor through a loudspeaker mounted on the standby sign. When the truck arrives at the entry gates D and E, the transport supervisor must ensure the trucks entering the gates are punctual i.e. in the right time slots. At gates D and E, all trucks are requested by the transport supervisor to provide the time slot numbers they booked for containers that are to be delivered or removed. Delays are mainly due to the verification of time slot numbers and the availability of lane positions in the system. Any late arrival by time slot booked trucks, will not be admitted into the entry gate and will wait in a single queue outside the terminal until another booking is requested by the truck to the management. There are four parallel lines numbered 1, 2, 3, and 4 respectively. Line numbers 1 and 2 are usually for trucks destined for the North Park and line numbers 3 and 4 are for South Park trucks.

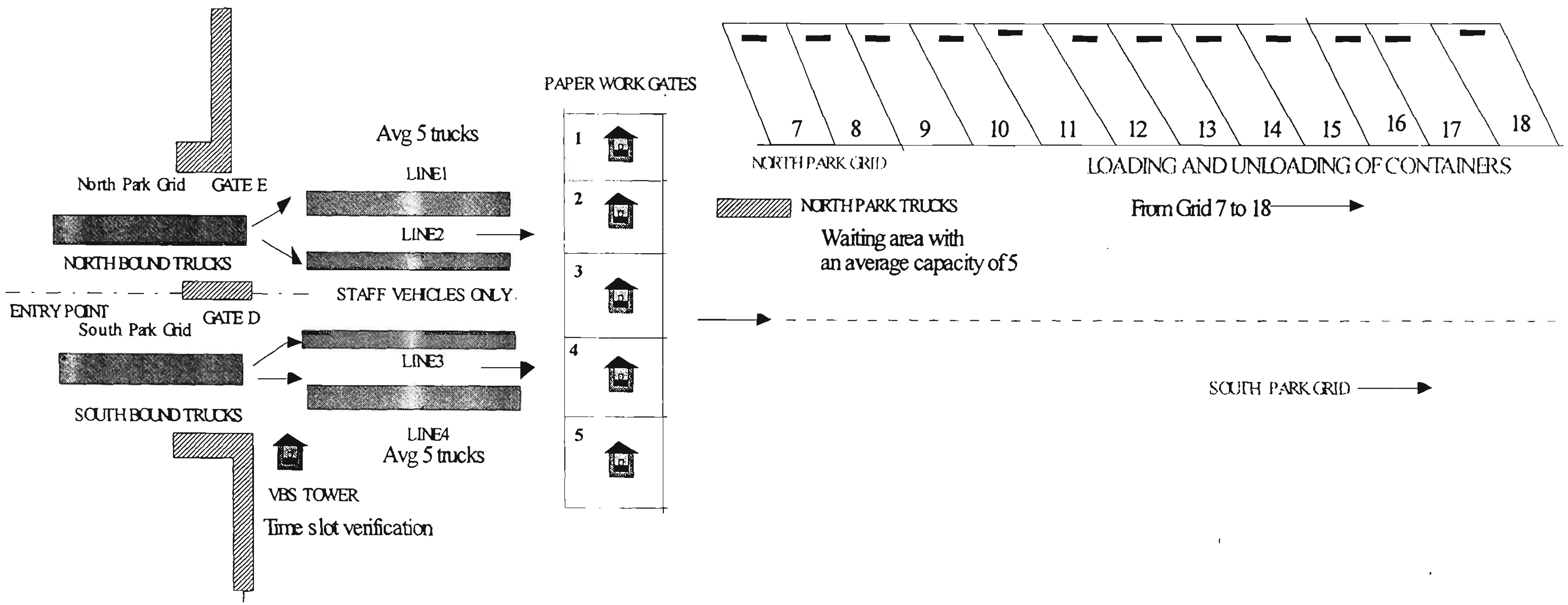


Figure 4.2 (a). Overview of container terminal gate system (north side of terminal).

Contd. diagram from previous page

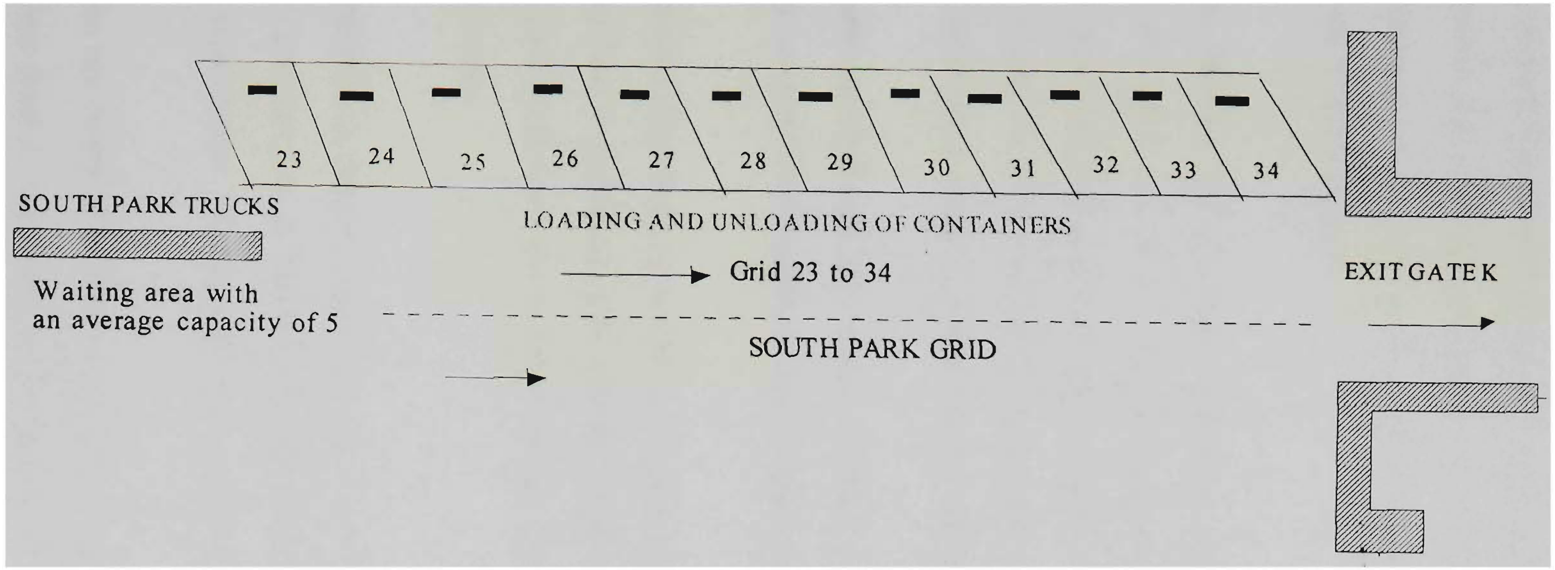


Figure 4.2 (b). Overview of container terminal gate system (south side of terminal).

The primary purpose of these lines is to provide waiting space for trucks whose movement through the terminal has been suspended based on the terminal's status. The capacity of each line is an average of 5 trucks. The entrance to the lines is denied when the queue is full in either of these lines. The Transport Supervisor, who is the authorised person to control the queue, then denies entrance of the late arrival trucks to the entry gate of the terminal.

Of immediate interest for the documentation process is a delay related to the allocation of five-gate resources. Clerks, who process related documentation and clearances of export or import trucks, operate all five resources (parallel gates). The allocation of trucks is directly related to availability of grid positions in North or South Parks. Allocation of gates is based on the following conditions:

- If both parks are full and the queues in both parks are full, then wait on lines proceeding to paper work gates for any of gates numbered from 1 to 5.

- If NP is empty (less than or equal to 11 grid positions), and the queue in North Park is less than 5, and there is no transfer of trucks to North Park, then seize gate 1 and 2 as first preference for documentation. The second preference is 3 or 4 or 5 if they are empty.

- If SP is empty (less than or equal to 11 grid positions), the queue in South Park is less than 5, and there is no transfer of trucks to South Park, then seize gate 3 or 4 or 5 as the first choice. The second choice is if gate 1 or 2 is empty.

- If both parks are empty (less than or equal to 11 grid positions), the queues at both parks are less than 5, and there is no transfer of trucks to both parks, then seize gate 1 or 2 for North Park and 3 or 4 or 5 for South Park trucks.

When the gate is idle, the inbound South or North Park truck will seize one of the gate resources for documentation process, which takes a few minutes. At the gate, delays are mainly due to transfer of data between the trucker and terminal. The delay time is different from gate to gate. The gate clerk will issue a transponder to every truck driver after the documentation process is over. A transponder is an electronic device used to identify of trucks in the truck grids by the straddle carriers. The gate clerk will feed the information of arrival of inbound trucks into the computer along with location of containers in the yard blocks, so that the straddle carrier computer will show what is the next job to perform in sequence order.

After the documentation process at the gates the trucks are moved forward towards North Park or South Park for retrieval or loading of containers. Each grid park has 12 ground positions. The flow of trucks to grid positions is controlled by the conditions described in the previous section. Upon arrival at the grid parks, a truck driver has to see whether all grid positions are busy, then wait in a queue marked specifically for each park. The logic is that at any time, all grid positions should be busy with trucks. The queue for each park has a capacity of five trucks due to limited space.

If any grid position is empty then the truck will seize the grid position. Then a request is sent to the corresponding straddle carriers, after the truck driver finishes the work of touching the transponder against the grid wall in grid position. A service event is scheduled to start for the grid positioned trucks for retrieval or loading of containers. If a straddle carrier is not idle, then the truck is placed in a queue list of straddles to wait for the corresponding grid park straddles. If a straddle is idle, the truck seizes the straddle, which imposes a delay equal to the time for pick up or delivery of containers from or to the trucks.

After loading or unloading services of trucks, all drivers must ensure that the containers on their trailers are locked properly before embarking from the grid. If there is any delay on the part of trucks after processing, the foreman in charge of grid parks will take all steps to avoid additional delays by the processed trucks.

The beginning of service for the movement to the exit gate K located on south side of terminal is scheduled after the trucks release the straddles. The container terminal has no exit gate system delay for either loaded or empty trucks. The loading and unloading facility of trucks operates 2 shifts a day for 5 days a week.

4.3. Overall objectives and issues to be investigated

The major objective of the study is to examine if the existing system components interact with each other effectively to produce the desired service level. When throughput (number of trucks completed per day) goals are not met, the terminal operator must identify ways of modifying the system to make it more efficient. Normally this is done by determining if there are bottlenecks in the terminal and then relieving them with more efficient equipment or procedures. Bottlenecks can be usually be observed by considering gate utilisation, North Park grid or South Park grid utilisation, and queue length. The objective is to develop a computer simulation model to analyse whether the gate system can meet the demands of trucks and how well the system performs using existing facilities.

The specific issues investigated in the study include the following:

- Total number of trucks processed daily.
- Average truck turn-around times.
- Average number of trucks in queue in a given time.
- Times trucks spend waiting for all queues
- Proportion of the time that the gates are busy.
- Utilisation of truck grids in North Park and South Park of the terminal.

4.4. Performance measures

This study is confined to a discussion of the major factors influencing the truck operation of a container terminals, as measured by turnaround time of trucks, grid occupancy (Utilisation), trucks processed daily, gate utilisation, and queue status. Achievement of a desirable level of truck service depends mainly on the length of turnaround time. The longer the turnaround time, the more the system will be congested.

In this study the turnaround time of trucks is determined by measuring the time interval from the trucks arrival to the entry gate of the system up to their departure from the system through exit the gate. The turnaround time is a sum of the waiting time of an arrival truck at the entry gates D and E, travel time from entry gate to a paper work gate, waiting time before seizure of a paper work gate, delay time for documentation at paper work gates, travel time from paper work gate to truck grids, waiting time on a park before seizing a grid, delay time on grids for loading and unloading of containers, and travel time from the grids to the exit gate of the terminal. However, the present system measures the time from the trucks' arrival to the paper work gates up to departure from grids after loading or unloading services. This shows the absence of generally agreed and acceptable definitions of turnaround time in terminal. However, the candidate has used both definitions (general and local) for this study and presents the results as per the local definition. The grid utilisation is expressed by the sum of the times the grids are used or occupied divided by the total number of grids. Average grid utilisation can be used to determine the number of grids needed in the North Park or South Park. The average gate utilisation can be used to determine the number of gates or clerks needed in the terminal. The gate utilisation is expressed by the sum of the gates which are busy divided by the total number of gates.

4.5. Data collection and analysis

Data were obtained on the operation of trucks from three sources, namely the electronic database of the system, observational data, and estimates made by the operational staff. The data obtained from the database was inadequate for the modelling studied. Instead the system was observed in operation and data were gathered by the candidate with care taken for independent observations without interfering with the daily routine of the terminal. Data observations in the truck grids of the terminal show that, in many cases, some drivers talk to each other after processing of trucks by straddles which leads to temporary blocking of grid positions for the next waiting trucks. The data were collected for several variables during the day and afternoon shift operation over a period over two months starting from 1st July to 7th Sept 1998; see Table 4.1 to 4.4. The data are represented as histograms are presented in Appendix C.

Table 4.1. Observations on the arrival of trucks and their time slot verification at the entry gate.

Variables	No. of data observed	Data range (min data value-max data value) in minutes	Sample mean	Sample standard deviation
Interarrival time (north bound trucks)	155	0.317-10.3	1.47	1.64
Interarrival time (south bound trucks)	120	0.167-13.60	1.83	2.3
Time slot verification at entry gate	128	0.083-1.28	0.274	0.174

Table 4.2. Data on documentation of trucks at gates.

Gates (delay time of trucks for paper work)	Observed data	Data Range (min data value-max data value) in minutes	Sample mean	Sample standard deviation
Gate No. 1	112	0.9-11.00	3.58	2.07
Gate No. 2	98	0.75-8.33	2.80	1.66
Gate No. 3	117	1.00-13.00	3.08	1.83
Gate No. 4	106	0.50-10.50	3.32	1.99
Gate No. 5	75	1.10-13.00	3.31	2.26

Table 4.3. Data on loading and unloading processes of trucks at the North Park grid.

Grid no. (loading and unloading delay of trucks	Observed data	Data range (min data value-max data value) in minutes	Sample mean	Sample standard deviation
Grid no. 7	81	1.90-46.00	13.6	9.99
Grid no. 8	76	1.75-38.58	11.40	7.71
Grid no. 9	75	2.20-51.00	13.70	9.32
Grid no. 10	77	2.75-60.00	14.90	10.40
Grid no. 11	77	2.75-60.00	13.70	9.00
Grid no. 12	75	3.83-66.33	16.30	12.00
Grid no. 13	76	1.50-49.50	17.40	11.4
Grid no. 14	75	3.00-75.00	18.80	18.8
Grid no. 15	76	3.00-48.00	16.90	10.3
Grid no. 16	75	4.00-48.00	17.20	10.4
Grid no. 17	71	2.90-63.33	17.00	11.2
Grid no. 18	44	2.58-56.50	16.60	12.8
Total	878	1.5-75.00	15.60 (avg.)	11.2 (avg.)

Table 4.4. Data on loading and unloading processes of trucks at the South Park grid of the terminal.

Grid no. (loading and unloading delay of truck at grid)	Data observed	Data range (min data value-max data value) in minutes	Sample mean	Sample standard deviation
Grid no. 23	66	3.00-44.00	19.1	19.50
Grid no. 24	67	5.5-88.50	17.1	11.9
Grid no. 25	67	3.57-84.7	18.00	13.4
Grid no. 26	66	2.33-51.00	17.40	11.10
Grid no. 27	68	3.67-116.00	21.00	18.00
Grid no. 28	65	3.67-80.00	18.30	12.40
Grid no. 29	65	2.83-68.00	18.20	12.00
Grid no. 30	66	3.5-54.30	19.00	9.86
Grid no. 31	65	6.00-47.00	17.60	9.11
Grid no. 32	64	3.83-72.00	21.30	13.80
Grid no. 33	48	8.00-80.00	20.10	12.90
Grid no. 34*	-	-	-	-
Total	707	2.33-116.00	18.60 (avg.)	12.5 (avg.)

Table 4.5. Route time of trucks in the terminal.

Truck routes	Average time during travel in minutes
From entry gate E/D to paper work gate	0.50
From paper work gate to north park grid	1.00-2.00
From paper work gate to south park grid	2.00-3.00
From north park grid to exit gate K	2.00-3.00
From south park grid to exit gate K	1.00-2.00

The following distribution functions are derived from observed data as shown in Table 4.6 to 4.9. An analysis has been carried out to check whether observed data are a good fit to theoretical distributions (see Appendix C for details) using standard statistical hypothesis tests. If the test fails to match the distribution functions to the data as described in Appendix C, an empirical distribution has been used to better capture the characteristics of the data.

Table 4.6 shows the empirical continuous distribution functions of time between arrival of trucks (interarrival time) for northbound and southbound trucks. The function for interarrival time of northbound trucks returns a value between 0 and 0.917 minutes approximately 48 percent of the time, a value between 0.917 to 1.833

* Grid No. 34 is not included for this study

minutes approximately 31.1 percent of the time (0.791-0.480 = 0.311 or 31.1 percent), a value between 1.833 to 2.75 minutes approximately 8.1 percent of the time, and so on. Similarly the empirical distribution function for the interarrival of southbound trucks returns a value between 0 to 1.40 minutes approximately 0.675 percent of the time and so on.

Table 4.6. Probability distribution functions for interarrival time and time slot verification at the entry gate of container terminal.

Variables	Parameter values of function	Distribution function expression
Interarrival (north bound trucks)	Empirical Continuous ($CumP_1$, Val_1 , $CumP_2$, Val_2 , ...)	CONT(0.00, 0.00, 0.480, 0.917, 0.791, 1.833, 0.872, 2.750, 0.905, 3.667, 0.932, 4.583, 0.946, 5.50, 0.980, 6.417, 0.986, 7.333, 0.986, 8.25, 0.993, 9.167, 0.993, 10.08, 1.00, 11.00)
Interarrival (south bound trucks)	Empirical Continuous ($CumP_1$, Val_2 , $CumP_2$, Val_2, ...)	CONT(0.00, 0.00, 0.675, 1.400, 0.800, 2.80, 0.892, 4.20, 0.917, 5.600, 0.950, 7.00, 0.975, 8.40, 0.983, 9.80, 0.983, 11.2, 0.992, 12.6, 1.00, 14.00)
Time-slot verification at entry gates	Lognormal (Mean, StdDev)	LOGN (0.269, 2)

Table 4.7. Probability distribution function for paper work of trucks at various gates.

Variables	Parameter values of distribution function	Distribution function expression
Gate No. 1	Lognormal (Mean, StdDev)	LOGN(3.57, 2)
Gate No. 2	Gamma (Beta, Alpha)	GAMM(0.941, 2.97)
Gate No. 3	Gamma (Beta, Alpha)	0.999 min + GAMM(1.47, 1.42)
Gate No. 4	Lognormal (Mean, StdDev)	LOGN(3.33, 2.12)
Gate No. 5	Lognormal (Mean, StdDev)	1 min + LOGN(2.36, 2.7)

Table 4.8. Probability distribution functions selected for loading and unloading processes of trucks at North Park and South Park grid of terminal.

Variables	Parameter values of distribution function	Distribution function expression
North Park (Grid no. 7 to 18)	Gamma (Beta, Alpha)	1 min + GAMM(7.6, 1.92)
South Park (Grid no. 23 to 33)	Gamma (Beta, Alpha)	2 min + GAMM(7.84, 2.12)

Table 4.9. Probability distribution functions used for route time of trucks in terminal.

Truck routes	Parameter values of distribution function	Distribution function expression
From entry gate E/D to paper work gate	-	Constant 0.50 min
From paper work gate to north park grid	Uniform (Min, Max)	UNIF(1.00, 2.00)
From paper work gate to south park grid	Uniform (Min, Max)	UNIF(2.00, 3.00)
From north park grid to exit gate K	Uniform (Min, Max)	UNIF(2.00, 3.00)
From south park grid to exit gate K	Uniform (Min, Max)	UNIF(1.00, 2.00)

Table 4.9 shows the distribution function for travel time of trucks. For example Uniform (1, 2) returns a value between 1 and 2 minutes.

4.6. Model development

The simulation model is developed using the industrial simulation software ARENA 3.0 i.e. academic version (ARENA User's Guide, 1996). Description of the model building process is provided in details in Appendix D. Priority has been given to the system logic which is used to control of truck movements within the terminal during the model building process, because the system monitors the number of trucks in all the queues within the terminal and sends requisitions, especially for a truck to move to parking grids, if the parks are available and idle and the number in the queue at each park is less than 5. This ensures that grids at both parks are never starved for trucks and that the queue at each park does not grow to extreme levels. A reason for monitoring this control could be limited waiting space in the terminal. Similarly the system also controls the trucks movement to four parallel lines preceding the second stage gates, called paper work gates, if the blockage is clear on all lines. Any additional trucks beyond the average capacity of 5 coming in must wait on the entry gate, preceding those lines. The following are assumed during model development stage:

- The trucks visiting the container terminal are either export or import type. However, there is no separate service strategy for these trucks. This model does not differentiate between for export and import trucks.
- Trucks using both north park grid and south park grid together are infrequent.
- Grid failures are negligible.
- Trucks having multiple trailers are not identified.
- Trucks' manoeuvring time before seizing of grids is negligible.

Therefore, none of these features is modelled. The model, called the basic model can be modified by the user and animation is used to portray the operation of the truck movements. Figures 4.3 (a) and 4.3 (b) show the truck operation layout output from ARENA package. Thirty replications can be run in eight to eleven hours on a PC fitted with a 200 MHz Pentium® processor with at least 32 MB memory using the Fast-Forward function of ARENA. The animation events are processed during the fast forward period, but they are not displayed on the screen.

4.7. Model validation and results interpretation of basic model

A number of validation checks have been performed on the truck movements in the system to ensure that the model is a good representation of reality. The model is analyzed for the terminating simulation because trucks operate 2 shifts a day (900 minutes) for a 5 days week. The results from the basic model are collected for a period of 30 days. The results are compared with the real system in Table 4.10. The results appear to match favourably.

Table 4.10. Comparison of model results with real system.

Identifier	Model	Real system	% difference
Average truck turnaround time in the system	23.86 Min	22.85 Min	4.42
Average number of trucks processed daily (North Park)	509	492	3.45
Average number of trucks processed daily (South Park)	374	384	-2.60

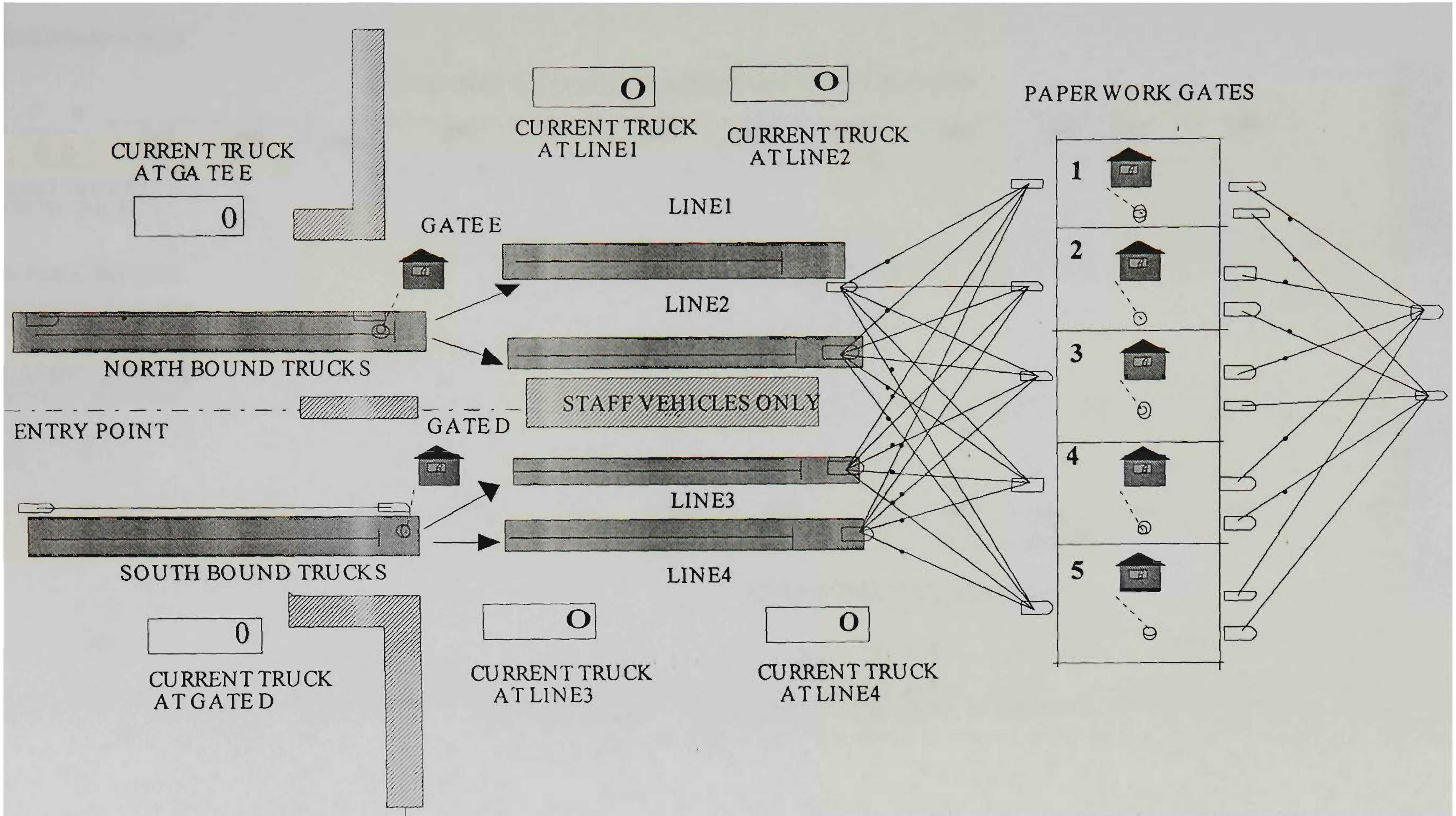


Figure 4.3 (a). Truck operation layout from ARENA.

Contd. from previous page

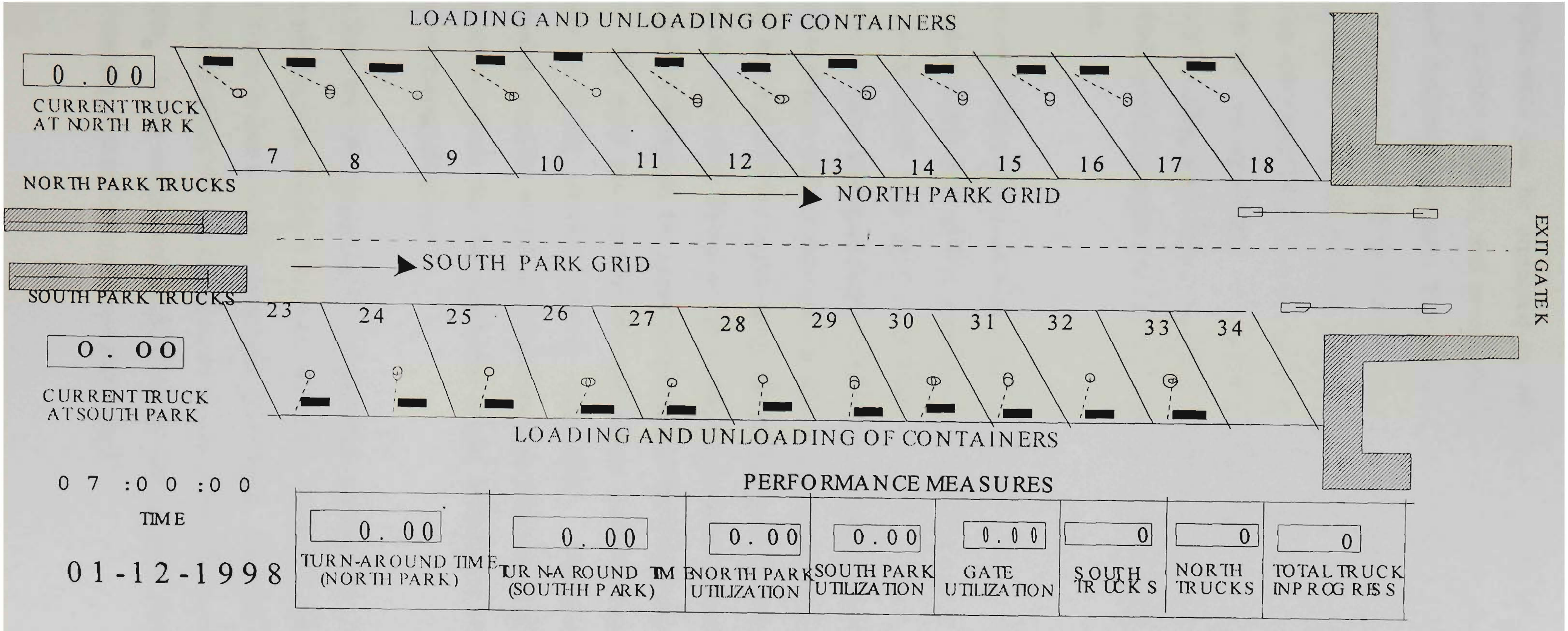


Figure 4.3 (b). Truck operation layout from ARENA.

The differences can be attributed to variations in the arrival pattern of trucks, processing time at gates, and processing time at grids, because the observed data fluctuates randomly each day. The actual turnaround time of trucks using both parks is higher than measured by the system, because the management is not considering the waiting time of trucks on all lines preceding to paper work gates and waiting time of trucks on entry gate D or E when all lines are occupied. In the research presented here, we are concerned only with system defined turnaround time. This indicates trucks are spending more time in south side of terminal (e.g. average 24.49 minutes in South Park grid) in comparison to north side (e.g. 21.49 minute in North Park grid) of terminal.

We can state with a high confidence (0.95) that the true expected turnaround time for trucks using North Park grid is between 21.27 minutes and 21.71 minutes and for trucks using South Park grid it is between 25.83 minutes and 26.63 minutes. Similarly, we have high confidence that the true but unknown value for the expected throughput in both parks is between 502 and 516 for trucks using North Park grid and between 368 and 380 for trucks using South Park grid i.e. about ±5% of our point estimate for this value. However, the confidence interval is a statement of reliability for our point estimate of the turnaround time and the total trucks passing through the system. We need not increase the replications from 30 because the model has produced a much smaller relative half-width. Therefore, our subsequent experimentation on the model does not include the calculation of confidence intervals because we conclude that the simulation model imitates the truck operation in the container terminal effectively.

Results from the basic model of the queue status, waiting time, number in the queue, and are presented in Tables 4.11, 4.12, and 4.13. Table 4.12 shows that the waiting time of trucks in line 4 is about 8 minutes on average. Essentially management is not too concerned about the waiting time of trucks before the paper work gates and at entry gates. In the subsequent analysis we do not consider these times because the average waiting time in both parks are quite small.

Table 4.11. Queue status within the terminal.

Identifier	Category	Occurrences		Standard Percent (%)
		No.	Avg. time in minutes	
Line no. 1	Empty*	20.6	44.957	96.48
	Partially full**	20.56	1.53	3.52
	Full	-	-	-
Line no. 2	Empty	502.86	1.544	86.36
	Partially full	502.86	0.242	13.64
	Full	-	-	-
Line no. 3	Empty	334.10	2.129	79.00
	Partially full	335.33	0.558	20.21
	Full***	3.7	1.90	0.79
Line no. 4	Empty	19.66	40.687	85.15
	Partially full	20.00	6.529	13.25
	Full	1.25	12.261	1.60
North Park	Empty	42.5	19.06	85.32
	Partially full	55.06	1.970	12.06
	Full	12.56	1.652	2.62
South Park	Empty	29.40	30.95	87.75
	Partially full	36.63	2.62	10.58
	Full	8.82	2.02	1.67

Table 4.12. Average waiting time of trucks in all queues.

Identifier	Average waiting time (min.)
Line no. 1	0.243
Line no. 2	1.49
Line no. 3	0.670
Line no. 4	7.62
North Park queue	0.55
South Park queue	0.58
Total waiting time for all queues	11.15 minutes

* The queue (0 nos.) changed into empty 20.6 times and spent an average of about 44.957 minutes in that state representing 87.75% of the run length.

** The queue (Up to 3 nos.) changed into partially full 20.56 times and spent an average of about 1.53 minutes in that state representing 3.52% of run length.

*** The queue (3 to 5 trucks) changed into full 3.7 times and spent an average of about 1.90 minutes in that state representing 0.79% of run length.

Table 4.13. Average # of trucks in all queues.

Identifier	# in queue (point estimate of 30 replications)
Line No. 1	0.137
Line No. 2	0.034
Line No. 3	0.27
Line No. 4	0.221
South Park Queue	0.248
North Park Queue	0.332
Total in all queues	1.24 nos.

Results from the above tables indicates that queue status, waiting time, and number in the queue of trucks are within control because the system controls the movement of road trucks due to limited waiting space in the terminal.

4.8. Numerical experiments and results

Nine different scenarios were identified by the management of the terminal for experimentation on the basic model as shown in Table 4.14. The experimentation is aimed at achieving a minimum turnaround time.

Table 4.14. Different scenarios with changing resources.

Scenario no.	No. of paper work gates	No. of grids in North Park	No. of grids in South Park
1	5	12	11
2	4	12	11
3	3	12	11
4	5	14	9
5	4	14	9
6	3	14	9
7	5	16	7
8	4	16	7
9	3	16	7

The above nine scenarios have been executed to test the effect of changing resources. Therefore, each experiment was replicated 30 times. The total number of simulation experiments performed is 9 (experiments) × 30 (replications) which totals 270. The results from all scenarios presented Table 4.15. Results from the table demonstrate that a minimum turnaround time can be achieved using 5 gates, 14 grids in the North Park (NP), and 9 grids in the South Park (SP) condition (scenario no. 4) with a total throughput of 883 trucks which is the same as of the present throughput of the system.

Table 4.15. Statistical presentation of a range of scenarios which indicates that scenario number 4 results provide the shortest turn-around time together with associated resource utilisations and total throughput.

Scenario no.	Avg. turnaround time (min)	Avg. gates utilisation (%)	Avg. NP utilisation (%)	Avg. SP utilisation (%)	Total throughput (trucks/daily)
1	23.86	63.91	68.29	65.29	883
2	26.47	77.69	69.00	60.86	867
3	37.43	86.97	67.43	41.54	743
4	23.39	64.26	69.27	64.91	883
5	26.11	76.86	68.32	61.53	862
6	37.07	87.23	68.67	41.19	747
7	23.48	64.69	69.42	66.43	876
8	26.11	76.92	67.97	64.07	860
9	37.3	87.06	68.47	41.87	745

Similarly experimentation on the basic model has been applied by varying the values of model's parameter and noting how these changes affect the behaviour of the model. The analysis is carried out by increasing the arrival rate of trucks from 10% up to 50% more than the present rate (by decreasing the interarrival time of trucks from 10% to 50% from the present rate). The 10% decrease of interarrival time of trucks is equal to 10% increase of arrival of trucks in the model. The results of the analysis are provided in Table 4.16. Increasing the arrival rate of trucks up to 30% improves daily throughput by an average of 126 trucks; however a further increase in arrival seems to have no significant effect on the number of trucks. This result points to some bottleneck in the facility.

Table 4.16. Experimental results: Additional trucks into the system.

% increase in arrival rates of trucks	Avg. daily throughput of trucks	Avg. turnaround time (min.)	Avg. gates utilisation (%)	Avg. NP utilisation (%)	Avg. SP utilisation (%)
0 (present rate)	883	23.86	63.91	68.29	65.03
10	949	25.29	69.42	73.69	68.70
30	1009	30.73	79.19	83.38	68.36
50	937	37.02	81.66	88.66	50.20

Table 4.17. Experimental results: gates idle, NP idle, and SP idle resulting from a 10% to 50% increase in arrival rate of trucks.

% increase in arrival rates of trucks	Avg. gates idle (%)	Avg. NP idle (%)	Avg. SP idle (%)
0% (present rate)	35.20	25.75	29.36
10%	29.00	20.58	24.90
30%	19.40	11.00	24.81
50%	17.00	5.58	45.45

Examination of Table 4.17 shows that the paper work gates and North Park (NP) grid are bottlenecks with very little idle time, and at the same time the idle time of South Park grid increases to a considerably. A major cause of lost throughput is the waiting time of trucks on lines 3 and line 4, which increases with the percentage increase in the arrival rate of trucks into the system. The reason for this increase in waiting time is the more frequent arrival of north bound trucks than south bound trucks into the lanes, waiting trucks on lanes entered into the second stage gates based on queue ranking rule FirstIn FirstOut, and the fact that processing time in the South Park grid is higher than in the North Park grid.

This suggests that we must explore a range of options that account for an increase in arrival rate with a simultaneous decrease in the processing time at grids by 10% to 50% compared with the present time. This will be discussed in section 4.8.1.

4.8.1. Response surface model

There is a need to investigate the functional relationship between the average value of a response, such as the average turnaround time, average total trucks, average North Park utilisation or South Park utilisation, and a number of variables x_{u1} and x_{u2}, such as the percentage increase in arrival of trucks and the percentage decrease in processing time. A general functional relationship of the form

$$\eta = f(x_{u1}, x_{u2}) \qquad [4.1]$$

may be proposed where η is a mean response and x_{u1} and x_{u2} are variables. In this particular problem, a polynomial approximation is very useful because the functional relationships of these variables are not known could be too complicated. A reasonable approximation might be expected by using a quadratic model which has the form (Box and Draper, 1987)

$$y = \omega_0 + \omega_1 x_{u1} + \omega_2 x_{u2} + \omega_{11} x_{u1}^2 + \omega_{22} x_{u2}^2 + \omega_{12} x_{u1} x_{u2} + \varepsilon \qquad [4.2]$$

where y represents the predictor variables or response variables, x_{u1} represents the arrival rate of trucks, and x_{u2} represents the processing time on grids. In the Expression 4.2, the ω 's are coefficients or parameters which have to be estimated from the data. In our study we have two inputs and the polynomial is of degree two, so we have six parameters.

The input or predictor variables are more conveniently used in the coded forms. The design was used to study y_i predictor variables such as average turnaround time, average total trucks, average North Park utilisation, and average South Park utilisation for a combination of two variables, each tested at two levels (see Table 4.18).

Table 4.18. Factors $Ø_i$ and coded levels x_{ui}.

Coded levels	x_{ui}	-1	1
Increase in arrival rate	$Ø_1$	0%	50%
Decrease in processing time	$Ø_2$	-50%	0%

It is convenient to code the lower and upper levels as x_{u1} and x_{u2} taking the values –1 for the lower level and 1 for the upper level. Thus,

$$x_{u1} = \frac{(Ø_1 - 25)}{25} \text{ and} \qquad [4.3]$$

$$x_{u2} = \frac{(Ø_2 - (-25))}{25} \qquad [4.4]$$

We note that the coded quantities x_{u1} and x_{u2} are simply convenient linear transformations of the original percentage increase in interarrival rate and percentage decreasing processing rate. So, an expression containing the x_{u1} and x_{u2} can always be readily rewritten in terms of the $\varnothing_1$ (Interarrival rate) and $\varnothing_2$ (decreasing processing rate).

Table 4.19 shows the uncoded and coded forms together with the response values y_1 (average turnaround time), y_2 (average total trucks), y_3 (average North Park utilisation), and y_4 (average South Park utilisation). The second degree polynomial in x_{u1} and x_{u2} is fitted to the transformed data by using the statistical computer program S-Plus (S+DOX™ User's Manual);

$$g(x_u,\omega) = \omega_0 + \omega_1 x_{u1} + \omega_2 x_{u2} + \omega_{11} x_{u1}^2 + \omega_{22} x_{u2}^2 + \omega_{12} x_{u1} x_{u2} + \varepsilon \qquad [4.5]$$

The coefficients are evaluated via the method of least squares for this particular set of 13 data values (Montgomery, 1997). The details of these coefficients and goodness of fit of the model are described in the Appendix E. If we denote the respective estimates by b_0, b_1, b_2, b_{11}, b_{22}, b_{12}, and the fitted values, that are the responses obtained from the fitted equation at x_{u1} and x_{u2} by $\hat{y}$, then

$$\hat{y} = b_0 + b_1 x_{u1} + b_2 x_{u2} + b_{11} x_{u1}^2 + b_{22} x_{u2}^2 + b_{12} x_{u1} x_{u2} \qquad [4.6]$$

For these 13 data values of average turnaround time, the coefficients obtained from this analysis are

$$\begin{aligned} b_0 &= 24.1750 \pm 0.2829 \\ b_1 &= 6.4140 \pm 0.2283 \\ b_2 &= -4.5850 \pm 0.1774 \\ b_{11} &= 0.7273 \pm 0.3719 \\ b_{22} &= 0.8416 \pm 0.3241 \\ b_{12} &= -0.4114 \pm 0.2535 \end{aligned} \qquad [4.7]$$

The numbers following the $\pm$ signs are the standard errors of the estimates.

Table 4.19. Simulation data in uncoded and coded units with responses y_1, y_2, y_3, and y_4.

Uncoded		Coded		Average turnaround time (y_1) in minutes	Average total trucks (y_2) in numbers per day	Average North Park Utilisation (y_3) in %	Average South Park Utilisation (y_4) in %
Percentage increase in arrival rate ($\varnothing_1$)	Percentage decrease in processing rate ($\varnothing_2$)	x_{u1}	x_{u2}				
0%	0%	-1	1	23.86	883	68.29	65.03
10%	0%	-3/5	1	25.29	949	73.69	68.70
30%	0%	1/5	1	30.73	1009	83.38	68.36
50%	0%	1	1	37.02	937	88.66	50.20
10%	10%	-3/5	3/5	23.40	974	69.37	62.76
10%	30%	-3/5	-1/5	19.59	986	54.61	52.37
10%	50%	-3/5	-1	17.16	993	46.37	40.91
30%	10%	1/5	3/5	29.54	1017	82.96	62.98
30%	30%	1/5	-1/5	24.22	1106	66.69	51.88
30%	50%	1/5	-1	21.79	1124	55.05	41.76
50%	10%	1	3/5	34.74	1000	85.76	47.30
50%	30%	1	-1/5	30.23	1094	76.54	37.92
50%	50%	1	-1	27.16	1150	64.77	31.29

Thus the fitted equation derived from the average turnaround time data is

$$\hat{y}_1 = 24.1750 + 6.4140\,x_{u1} - 4.5850\,x_{u2} + 0.7273\,x_{u1}^{\ 2} + 0.8416\,x_{u2}^{\ 2} - 0.4114\,x_{u1}x_{u2} \qquad [4.8]$$

For comparison, the $\hat{y}_1$ is evaluated from the fitted equation by substituting the x_{u1} and x_{u2} values are shown beside the actual observed y_1 (average turnaround time) in Table 4.19. Figure 4.4 shows contours of the fitted equation for $\hat{y}_1$ in the x_{u1} and x_{u2} computed from Equation 4.8.

Similarly, coefficients obtained from the analysis for 13 data values of average total trucks, and their standard errors are

$$\begin{aligned} b_0 &= 1069.8058 \pm 6.3747 \\ b_1 &= 82.5700 \pm 5.1452 \\ b_2 &= 52.9147 \pm 3.9986 \\ b_{11} &= -83.9312 \pm 8.3812 \\ b_{22} &= -20.9161 \pm 7.3036 \\ b_{12} &= 53.6793 \pm 5.7119 \end{aligned} \qquad [4.9]$$

The fitted equation derived from these data is

$$\hat{y}_2 = 1069.8058 + 82.5700x_{u1} + 52.9147x_{u2} - 83.9312x_{u1}^{\ 2} - 20.9161x_{u2}^{\ 2} + 53.6793x_{u1}x_{u2} \qquad [4.10]$$

The relationship between an average total trucks and two quantitative variables x_{u1} and x_{u2} are represented by contour plot, as illustrated in Figure 4.5.

Similarly, for the North Park utilisation data values, coefficients and their standard errors are as follows.

$$\begin{aligned} b_0 &= 68.6763 \pm 1.3160 \\ b_1 &= 12.4704 \pm 1.0622 \\ b_2 &= -14.1607 \pm 0.8255 \\ b_{11} &= -2.9601 \pm 1.7302 \\ b_{22} &= -0.8336 \pm 1.5078 \\ b_{12} &= 1.4571 \pm 1.1792 \end{aligned} \qquad [4.11]$$

The fitted equation derived from these data is

$$\hat{y}_3 = 68.6763 + 12.4704\,x_{u1} - 14.1607\,x_{u2} - 2.9601\,x_{u1}^{\ 2} - 0.8336\,x_{u2}^{\ 2} + 1.4571\,x_{u1}x_{u2} \qquad [4.12]$$

The contours of this fitted equation are shown in Figure 4.6 obtained from Equation 4.12.

Similarly for the data values of South Park utilisation the estimated coefficients and their standard errors are as follows

$$\begin{aligned} b_0 &= 56.1081 \pm 0.5419 \\ b_1 &= -4.3411 \pm 0.4374 \\ b_2 &= -12.8332 \pm 0.3399 \\ b_{11} &= -11.2721 \pm 0.7125 \\ b_{22} &= 0.2860 \pm 0.6209 \\ b_{12} &= 2.5661 \pm 0.4856 \end{aligned} \qquad [4.13]$$

The second-degree equation fitted is

$$\hat{y}_4 = 56.1081 - 4.3411\,x_{u1} - 12.8332\,x_{u2} - 11.2721\,x_{u1}^{\;2} + 0.2860\,x_{u2}^{\;2} + 2.5661\,x_{u1}x_{u2} \qquad [4.14]$$

Figure 4.7 shows contours of the fitted equation for $\hat{y}_4$ in the x_{u1} and x_{u2} computed from Equation 4.14.

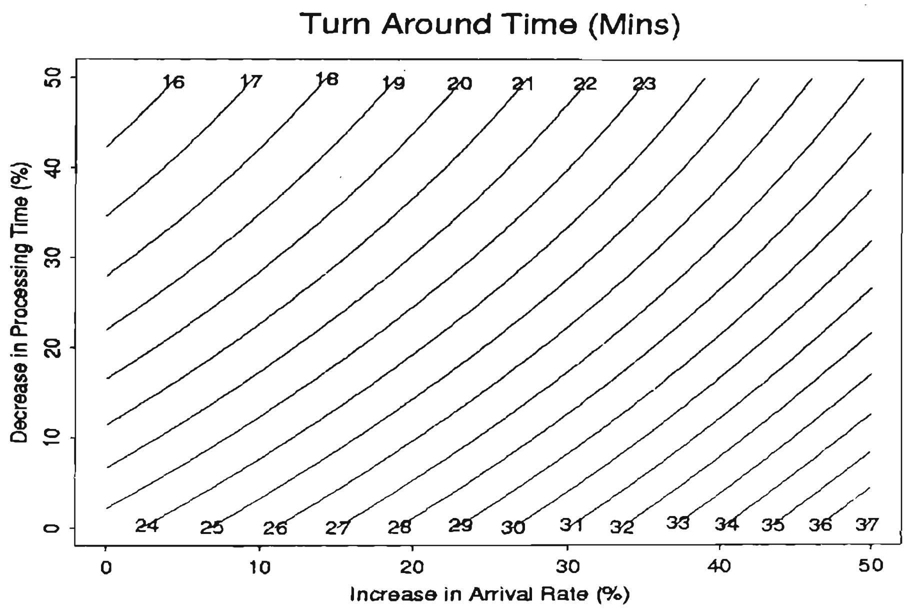


Figure 4.4. Contour representing turn-around time (minutes) versus increase in arrival rate of trucks and percent decrease in processing time at grids.

As can be seen from the contours in Figure 4.4, the turnaround time decreases from the lower right to the top left corner of the diagram, as we progressively decrease processing time at the grids and simultaneously increase the arrival rate. As can be seen in the same figure, a decrease of 20 to 30 percent of the processing rate causes a 20 to 18 minutes decrease in the total turn-around time from the present rate of 23.86 minutes with simultaneous increase in arrival rate up to 10%.

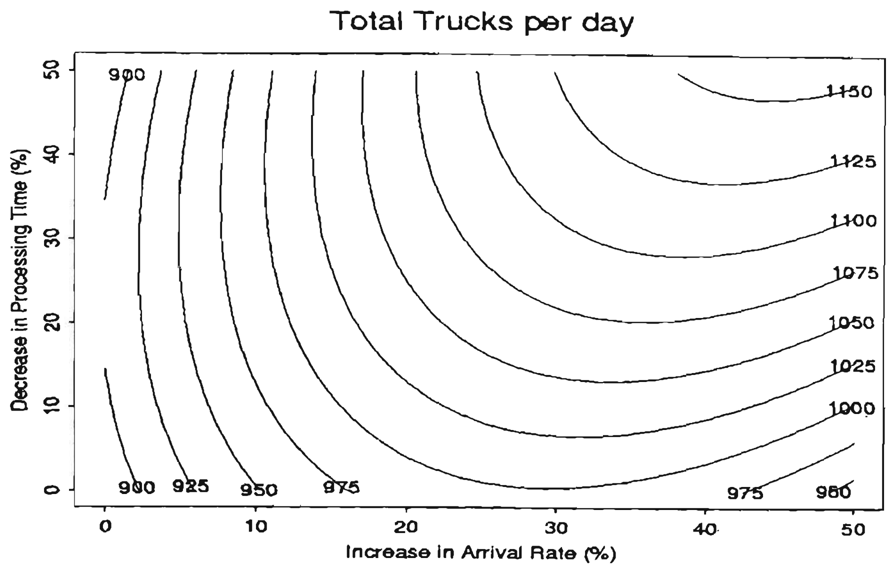


Figure 4.5. Contours representing total throughput (trucks/day) versus an increase in the arrival rate of trucks and percent decrease in processing time of trucks at the grids.

Figure 4.5 shows that the number of trucks processed per day is relatively insensitive to a decrease in processing time on the grids at the present arrival rate of the trucks. Processing time becomes more important as the rate of arrival of the truck increases. It can be seen that the throughput (average total trucks) is about 1150 trucks per day when the arrival rate is increased by 50% and the processing rate on the grids is decreased by 50%.

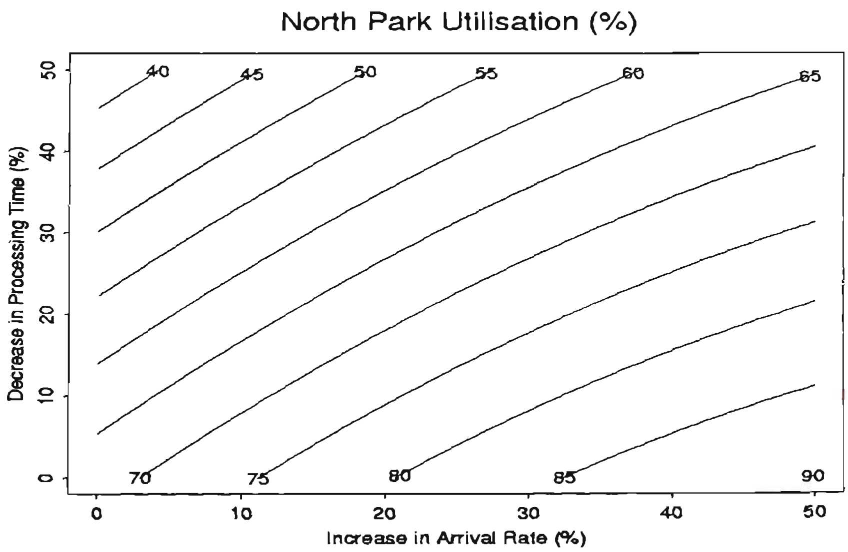


Figure 4.6. Contours of average North Park utilisation (%) for percent increases in the arrival rate of trucks and percent decreases in the processing time at the grids.

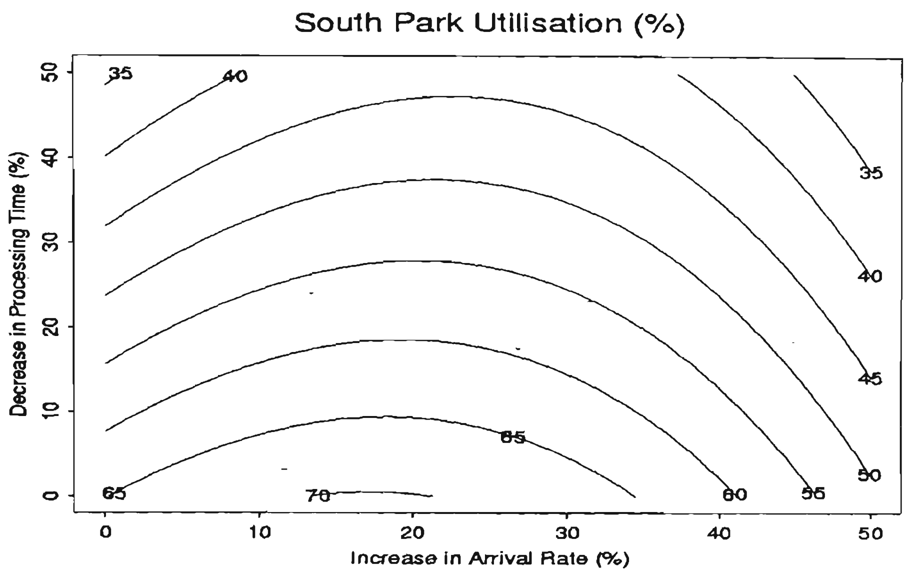


Figure 4.7. Contours of average South Park utilisation (%) for percent increases in the arrival rate of trucks and percent decreases in the processing time at the grids.

Figures 4.6 and 4.7 show how decreasing the processing time decreases the utilisation of both the North and the South parks over a range of arrival rates of trucks. The results, shown in Figure 4.8, enable turnaround time, total trucks, North Park utilisation and South Park utilsation to be observed as functions of arrival rate and truck processing time in the grids.

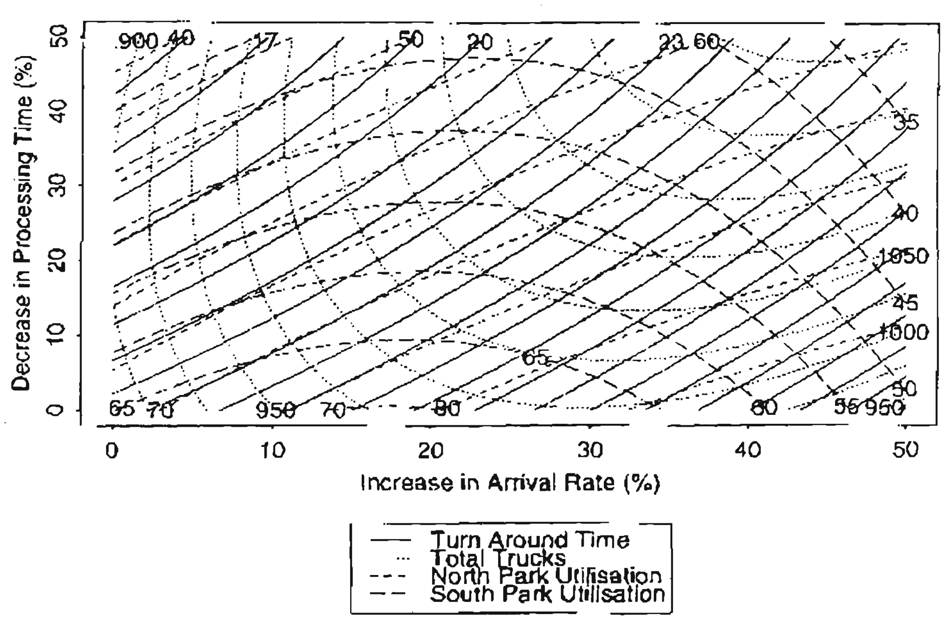


Figure 4.8. Contours of total throughput (total trucks/day), average NP utilisation (%), and average SP utilisation (%) superimposed on those for average turn-around time (minutes) of trucks.

It can be seen that by decreasing the processing rate by 50% with a 10% increase in trucks arriving the turnaround time is 17.2 minutes. Furthermore the container terminal can handle 993 trucks per day. If the arrival rate of the trucks increases by 30% the throughput of the trucks is 1124 trucks per day and turnaround time is 21.8 minutes. A reduction on the processing time of trucks improves the overall system performance considerably and allows a reasonable compromises between high system utilisation and the short turnaround time and total throughput.

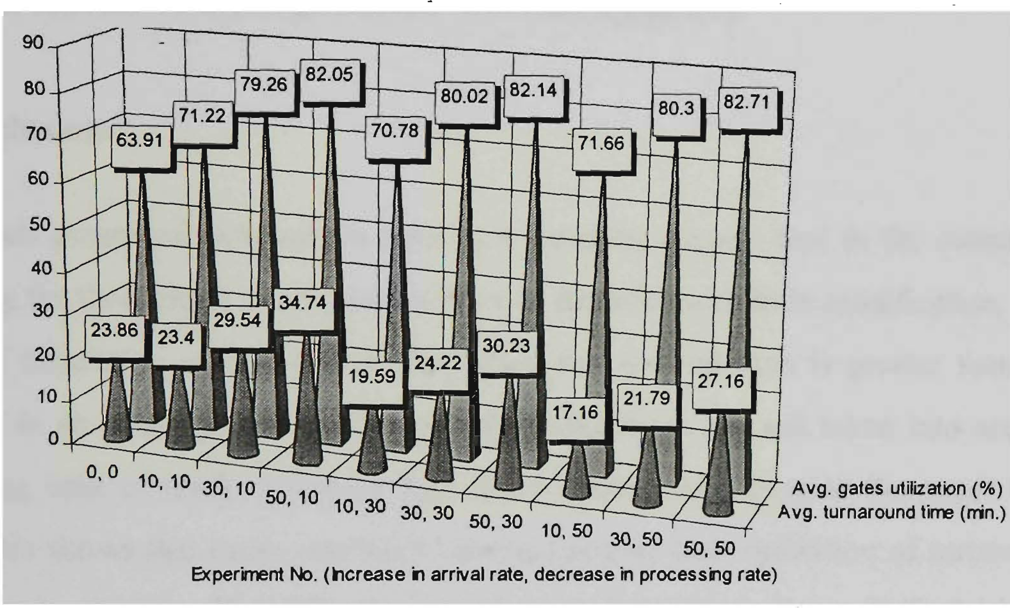


Figure 4.9. Experimental results for increase in arrival rates of 10% to 50% and 10% to 50% decreases in processing rates from the present set-up: average turnaround time, average utilisation of gates.

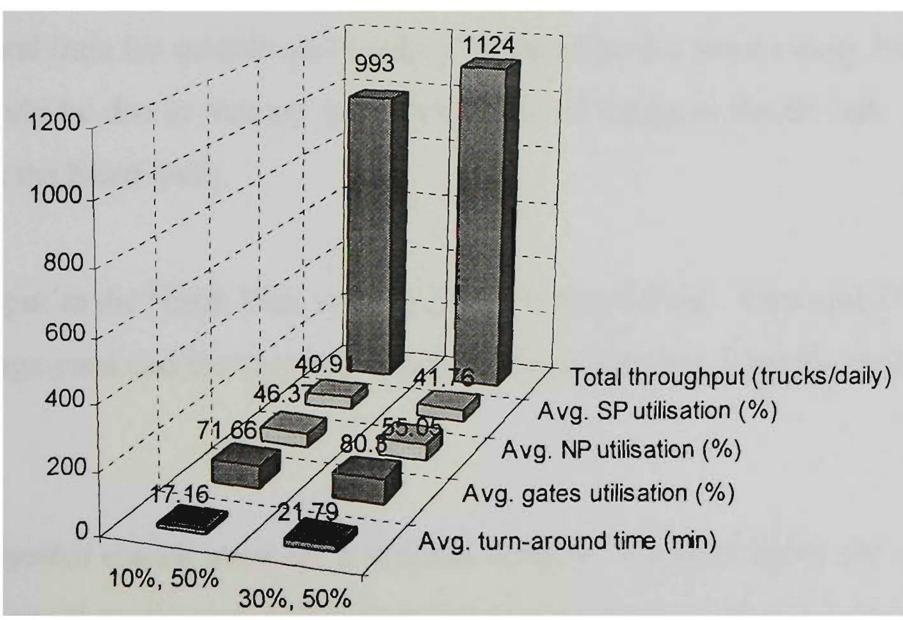


Figure 4.10. Statistical comparison of a 10% increase and 50% decrease, and a 30% increase and 50% decrease in arrival rate and processing time respectively.

Figure 4.9 highlights results obtained for the effects on the utilisation of the paper work gates and truck turnaround time as a function of the arrival of trucks and the processing time in the grids. An increase of 30% in arrival rate and 50% decrease in processing time is more effective than a 10% increase in arrival rate and 50% decrease in processing time because this is the compromise between total throughput and system utilisation and the short turn-around time; see Figure 4.10. It should be noted that increased processing time at the grids can be achieved by increasing the number of straddle carriers. A cost is associated with such equipment.

4.9. Conclusions

The models presented here can be seen as a decision support tool in the context of improving the throughput in any similar type of facilities with little modification. The results of simulation models reveal that actual turn-around time is greater than that measured in an existing system because the management has not taken into account the waiting time of trucks spent on four lanes before proceeding to the paper work gates. This shows that every container terminal has its own definition of turnaround time of road vehicles. The following conclusions have been drawn from the above results:

The turn-around time for southbound trucks is higher than for trucks using North Park grid. This could be due to average processing time of trucks in South Park, which is higher than in the North Park.

Total throughput in the North Park is more than the South Park. This could be due to the large storage yard and the fact that less straddle carriers are allocated to the South Park.

The existing system cannot meet the additional demand of trucks unless the operation management speeds-up the processing time in both parks, especially in the South Park grid.

Minimum turn-around time of road vehicles can be achieved by re-allocating resources from the present set-up. This can be best achieved with 5 gates, 14 grids in North Park, and 9 grids in South Park without changing the present average throughput of 883 trucks per day.

A throughput of 1124 trucks can be achieved with a 30% increase in arrival rate and a 50% decrease in processing time to achieve an average turnaround time of 21.8 minutes from the present set-up.

Additional handling equipment (straddle carriers) is required in both parks in order to achieve a throughput higher than 1124 trucks per day, because the present logistical operation of the movement of the trucks is very close to being optimal. However, if it is wished to increase the throughput of the terminal, a bottleneck occurs in loading and unloading the containers on and from the trucks.

The need to employ additional straddles is discussed in chapter 5 where it is shown that processing time is directly related to the number of straddles and their effectiveness for handling the trucks on grids.

CHAPTER 5

SIMULATION MODELLING OF STRADDLE CARRIER OPERATIONS BETWEEN THE TRUCK GRID AND THE YARD AREA OF A TERMINAL

5.1. Introduction

The preceding chapter has described the simulation modelling of the road vehicle operations in a terminal. It is concluded that faster clearance of trucks from grids depends on how effectively they are served by container handling equipment such as straddle carriers. In recent years straddle carriers have been increasingly used in Australia because of their operational flexibility and multi function handling capability. However, the control of the operations of straddle carriers for an existing terminal layout are not an easy task because scheduling, routing, and layout must all be considered at the same time. The number of papers on simulation applications in container terminals is significant (see for example [Hedrick and Akalin 1989, Kondratowicz 1990, Mosca *et al.* 1994, Gambardella *et al.* 1996, 1998, Ramani 1996, and Nevins *et al.* 1998]). The number of innovative applications of straddle carrier simulation is much lower. However, some of the important contributions to this area are summarised below.

Teo (1993) has developed a simulation model for the landside operation of a container terminal located in Singapore using automated guided vehicles (AGV) for container movements. This study is concluded with the difficulties and limitations of developing the model using Simscript™ and Simgraphics™, with no disclosure of data and simulation methodology. Koh *et al.* (1994) have introduced a model for prime movers (PM) in the Port of Singapore Authority's container terminal. In their opinion a detailed model which incorporates acceleration and deceleration of the vehicles would not necessarily give better results, because the vehicles are manually operated. Their model used constant average speeds of vehicles to model the various transit times. Ballis and Abacoumkin (1996) have developed a computer simulation model with on-screen animation graphics, which can simulate operations of a container terminal equipped with straddle carriers. The model takes into consideration the acceleration and deceleration of straddle carriers, but it does not include straddle failures. In their studies there are different heuristic rules such as first come, first served discipline, or the work list is assigned to the idle straddle carrier that is closer to the truck position such as in the Port of Piraeus.

In some ways, the modelling of the movement of straddle carriers is akin to the modelling of automated guided vehicles (AGV) which are driverless and which follow guide wires embedded in the floor. The principal difference is that straddle carriers have drivers who must obey certain traffic rules but whose jobs are assigned by computer. A controlling computer system usually directs the AGV from one point to another point, whereas a driver of a straddle carrier in a terminal drives the vehicle between destinations on a straddle route. However, the literature review highlights that AGVs are widely used in manufacturing or assembly systems for material handling. Many simulation studies have been conducted in the past to evaluate material handling in production systems for better control (see for example [Maxwell and Muckstadt 1982, Newton 1985, Egbelu *et al.* 1988, Pulat and Pulat 1989, Lee *et al.* 1990, Mahadevan and Narendran 1990, Bozer and Srinivasan 1991, Choi *et al.* 1994, and Lee 1996]). However, the operation of container terminals and manufacturing systems is quite different in terms of its objectives and work environment. We were of the opinion that a detailed literature review in AGV simulation would not necessarily be of interest to container terminal operators. There are very few container terminals in the world equipped with AGV control container handling system. Evers and Koppers (1996) have conducted one such study in the context of traffic control at a container terminal located in Rotterdam.

Most papers do not describe the details of the models. At most, a simplified description of simulation software is provided rather than the actual applications. Most simulation models reported in the literature differ widely in their objectives, detail, and the factors they take into consideration. Hayuth *et al* (1994) note that the objective may be planning, better operation, or an analysis of existing operations; the majority fall into the planning category. There is no one simulation that is better than another for every situation, since such factors as complexity and detail are dictated by specific circumstances, which differ from case to case. The issue of increased realism in modelling continues to be an important one. In addition the operating conditions of each terminal are different and past experience from other container terminals may not be exactly applicable to the present generation of container terminals (Beemen and Vallicelli 1975, Lacey 1980, PDI 1988, Stempel 1991, Ballis and Abacoumkin 1996).

The objective of this chapter is to evaluate the performance measures with multiple straddles and test various parameters in the existing layout including the number of straddles needed, straddle speed, job assignment rules and increasing the arrival rate of trucks on grids. This study also compares the performance of proposed heuristic job assignment rules of straddles with the present job assignment rules.

5.2. Truck grid operation

The container terminal at West Swanson Dock has a straddle carrier based service system that transfers the containers from the truck grid of North Park/South Park to yard, and vice versa. Trucks, whether they be export/import, enter the terminal through a set of "paper work" gates and drive up to the specified service area called North Park grid or South Park grid. At both the North and South Park grids, the truck driver has to occupy one of 12 ground slots for loading/unloading containers. This study is confined to the North Park yard area because all reefer containers are received and delivered to this grid and it is also larger. After a truck joins the truck grid, road receival (RR) and road delivery (RD) services can commence.

The flow of trucks into the terminal depends upon the arrival date of vessels. As soon as a vessel's arrival is known, its agents inform the terminal operator and forward an export projection statement and an import bay plan. This export projection statement gives all the details of the containers to be loaded on board the vessel. Then the terminal operator asks its clients to send the export containers to the terminal. The management has permitted five days excluding weekends for road RR (export) and four working days excluding weekends for RD (import). RR stops once the vessel arrives at the specified berth.

5.3. Container transfer

The terminal uses straddle carriers, which both handle and transport containers in the yard and wharf areas (see Figure 5.1). In reality, the movements of containers within the terminal start with a request for an available straddle carrier at truck grids, where trucks carrying containers are in queues. The truck driver plugs the transponder (issued at the "paper work" gates) into a small concrete wall at the grid, which identifies the location of the truck and assigns the job to the straddle with the least number irrespective of its distance from the truck grid. If the straddle with the least number is busy, the next available straddle is assigned to load/unload the containers of that truck. However each truck is granted one straddle at a time for receival/delivery irrespective of the number of containers it is carrying. If there is no truck on the grid, the idle straddle is parked near the grid area. The allocation is dynamic since straddle carriers are moved and new trucks are coming to be served. How the job is assigned to a straddle is shown in Figure 5.2.

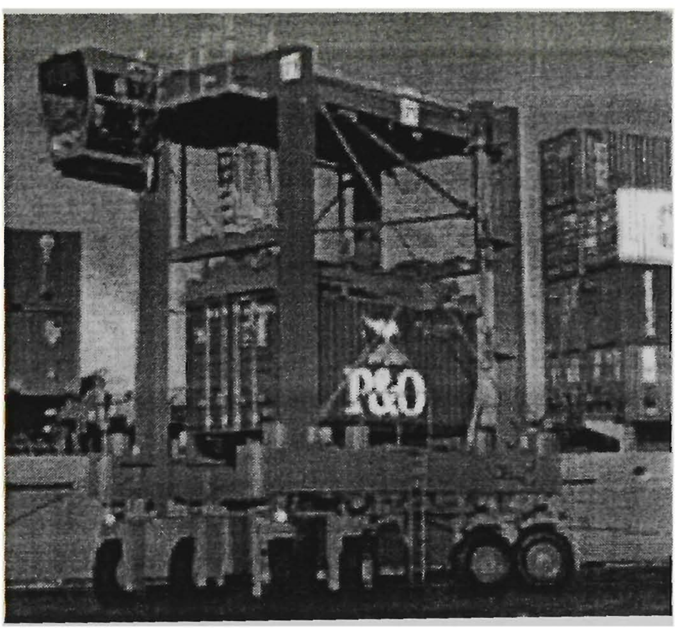


Figure 5.1. A straddle carrier.

For example, straddle N16 is performing the delivery of a container (20ft size) from North Park of row 'L', slot number 23 and two high (location) to truck no. KEN 400, which is identified by the transponder number (see Figure 5.2). The system attempts always to select the available straddle with the lowest number [i.e. defined as the preferred order rule (POR)]. However the system does not allocate the straddle closest to the requesting truck in the grid.

```
CTDTE00G v1.0           CONTROL TOWER MONITOR              USER ID: MGP
N16, T20, T21, T25, T29 Scheduler up Bat reader up IY moves=0 IY queues=0
No locked rows
Mach Gr    Container    Size Ves From     To      Rego     Remarks

     18    WLNU4109609 2210 TAR NLY151  BRO     LA770
T29  11    GSTU5903226 2210 TAR NLV182  AB7     MACK00   ON FRONT
     11    WLNU4107463 2210 TAR NLV113  AB7     MACK00   ON REAR
     11    MAEU7784149 2210 MEO AB7     NJV182  MACK00
N16  7     GSTU2589430 2210 TAR NLX232  DM5     KEN400
     7     CRXU2977640 2210 TAR NLY171  DM5     KEN400
T20  13    UXXU2328147 2210 CSH NOH091  AM4     PBD026
T21        FESU2031940 2210 KAV NLT162  NLT191
     8     TRIU3977269 2310 YOY NLT161  AF4     OAX641
T25  9     YMLU7406356 2232 ZSD AO9     NNG212  FLO620
     15    MMMU7359826 2210 KBN AX4     NJW171  OPS419
     14    MMMU7398247 2210 KBN CL2     NJW171  PWF959
     17    MAEU2402639 4310 PSU NNT152  BH6     NAE526
     10    SCZU8665730 2332 YOY NLD202  CT3     FSI320
     16    TEXU3038230 2200 GTB NLM211  BO1     PAM213
           TRIU7503165 4332 AUR NOW221  CTO     OLH697
NORTH      Press command key:
```

Figure 5.2. Job schedule of straddle carrier in North Park.

After an idle straddle is chosen, it must travel from its current position to the container pickup point. The pickup point may be a grid of North/South Park, a ground slot in the yard area or a ground slot in the wharf area. Only then can the container be loaded onto the straddle and the actual transfer take place. This principle is applicable irrespective of export and import containers.

The straddle carrier cannot freely move about the container terminal because the limited space gives rise to obstructions that delay its progress that is, the terminal is restricted to pre-defined movements due to its confined space. The travel time for a straddle varies with its velocity, acceleration, deceleration, the route configuration, the route that the straddle follows, and the congestion caused by the other straddles. The terminal has a speed limit of 20 km/hr for all straddles. However, the straddle can travel at its design speed of 25 km/hr in an unrestricted route. It was observed during this study that straddles were travelling as slowly as 9 km/hr in restricted routes and yard blocks because the West Swanson Dock is a terminal with a high traffic density in a small yard and therefore the management of space is a critical issue.

Two sets of straddles perform a range of activities in the terminal, namely landside interface (integration of the truck grid and yard area) for road receival and road delivery, while the other set is used for seaside interface (integration of yard area and wharf) for quay cranes.

In the landside operation, management usually assigns six straddles to North Park and five straddles to South Park respectively. The assignment is based on the number of time slots and availability of straddles. It is concluded that the allocation is also based on performance of the straddles. Straddle performance between grids and yard operations is shown in Figure 5.3.

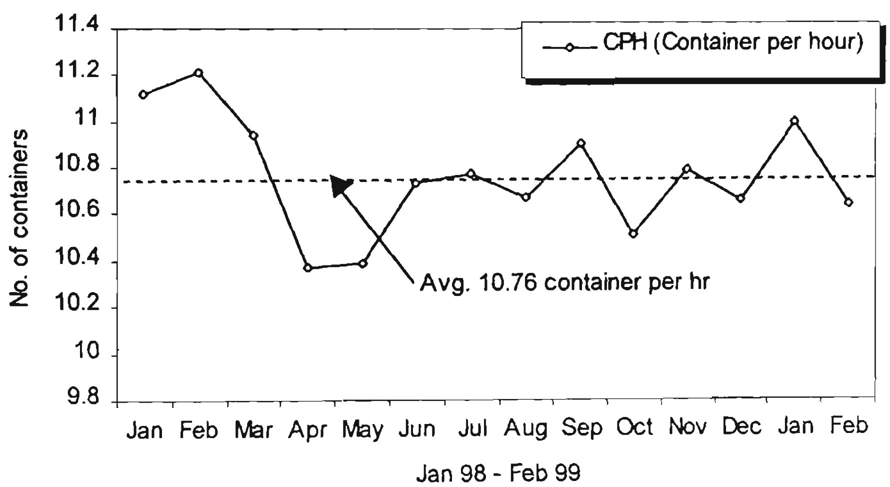


Figure 5.3. Average handling rate of a straddle carrier in landside operation.

The stacking area for containers has many rows, with many containers in each row, while paths are wide enough between container rows to accommodate the legs of straddle carriers that are moving inside the stack area. Due to the above container arrangement each yard area has north to south access capabilities due to physical restrictions. However some yard areas have access east to west of the terminal due to space issue problems, except yard area H5 which has dual access capabilities. Figure 5.4 shows the accessibility for straddles in yard areas of the terminal.

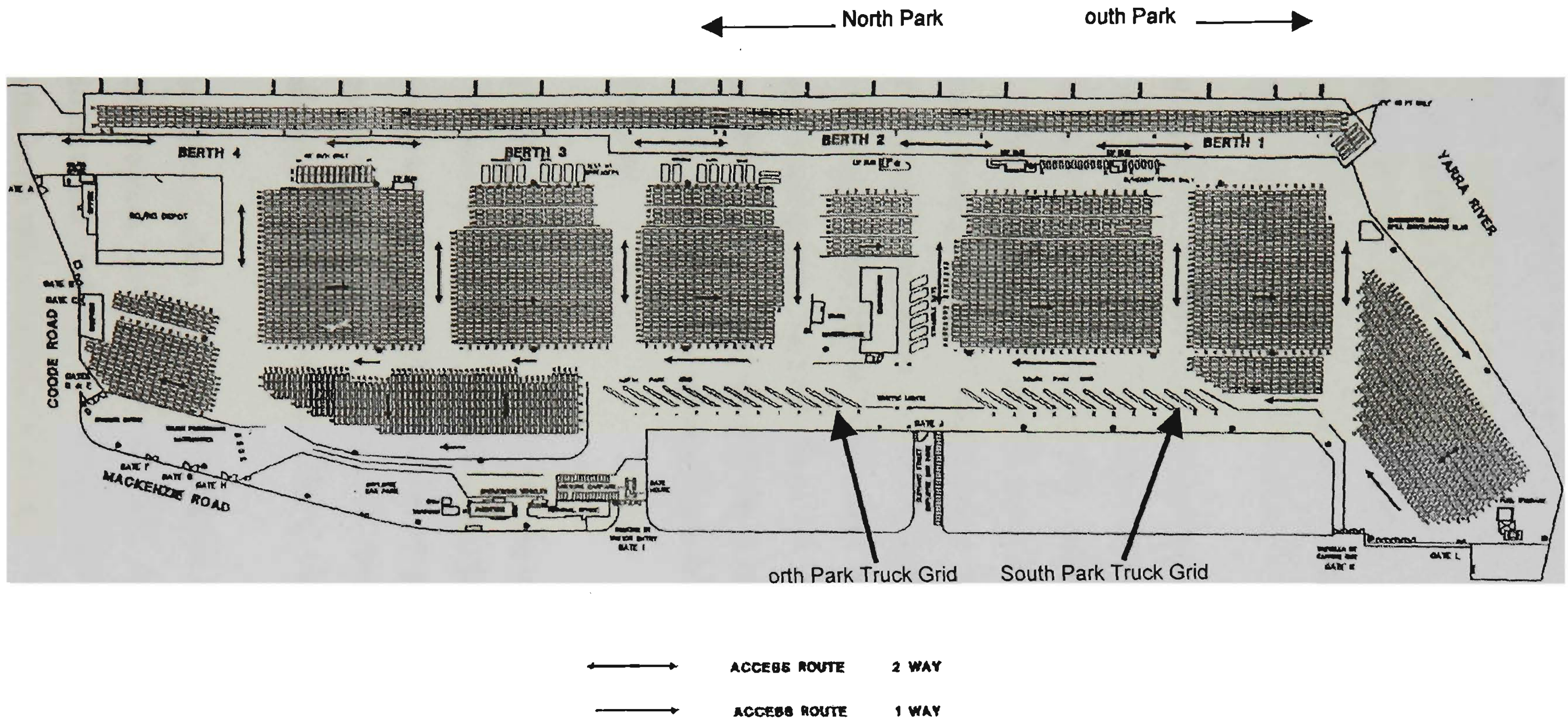


Figure 5.4. Straddle carriers access route between the truck grid and yard area of container terminal.

5.4. Container storage system

The yard operation is the busiest part of terminal. The operation involves discharging of containers from vessels, loading of containers onto vessels, shuffling of containers that are out of sequence in yards for more efficient road delivery/receival and efficient loading of vessels. The yard planner who decides the allocation of yard area does not discriminate between export and import. The allocation rule of one day is not the same as for the next day. The storage system consists of two parks called North Park and South Park. Each park consists of number of blocks as shown in Figure 5.5.

The allocation in the yard area depends upon road recival and delivery. If it is delivery, L and M rows (E4 Yard) are primarily for import containers, because of their close proximity to the North Park grid and hence the straddles only have to travel short distances to grids. If the capacity of L and M rows (E4 yard) overflows, then import containers are assigned some portion of P and O rows. Yard F5, which consists of H, J, and K rows, is used for export containers. Yard H5, which consists of Q and P rows, is for half of the time in a month, used by RO-RO cargo. When there is no RO-RO cargo, empty export containers are usually stacked. Yard G4, which consists of P and O rows, contains on average 30% import containers and the remaining export containers. Yard G2, which consists of W rows, stores over-dimension containers with no discrimination between export and import.

Yard F3 consists of NB to NG rows which are for export and import reefers. Yard F4 consists of X and N rows which are for export and import. Yards D3 and C3, which consist of G and D rows are for reefer export and import containers. Yards E3 and E2 are for export and import reefer containers. It has been observed that hazardous containers under various classes are placed separately in different yard areas.

The terminal handles class 2, class 3, class 4, and class 5 hazardous containers. However storage yard handles reefers, over-dimension, high cube (height 9’6”), and general containers. It is also seen that yards closed to the landside are usually allocated to import, and yards closer to the berth side are allocated to export containers.

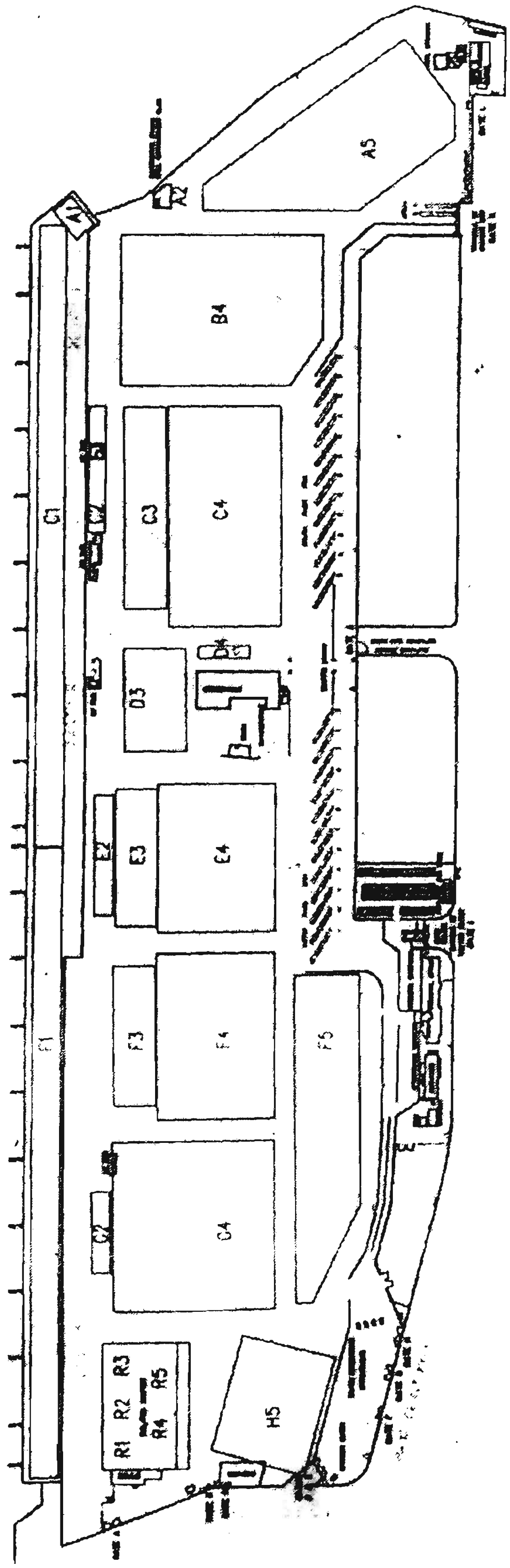


Figure 5.5. Yard blocks with identification codes in a terminal.

The yard planner can stack containers up to three high, but due to the restricted height under the straddle spreaders the straddle can only stack quite comfortably two high and can pass over a two high stack with a container.

As a result, in normal and intensive work periods, some parts of the storage areas are allocated to export and import containers with wide variation. To quantify these variations is a difficult and complex task, because there is no official allocation strategy which can be applied for everyday operation of the yard. Every yard planner's views are different when decisions relate to yard allocation.

Interviews indicate that allocation (yard planners') decisions are based on their experience and take into account the yard distance from the truck grid, the work pressure, the slot position in the yard area and possible traffic problems caused by the straddles.

Storage areas are divided into stacks for various types of containers and stacks are divided into rows. Each container position has a code number that gives the address (storage area, stack, row and height) of the container in the terminal. Also the parking places in the truck grid have a similar code number. This provides an accurate and quick way of referring to the movement of a container between origin and destination position.

5.5. Objective of simulation modelling

When more straddles circulate in the terminal, decisions regarding traffic flow patterns along the straddle routes, and straddle dispatching have to be made. In terminals, problems of congestion and straddle interference need to be solved. When a container visits one of the yard areas before its destination, the requirement of a straddle is time-phased. As the number of containers in the system increases, the problem becomes intractable, and needs to be analysed by simulation. Estimating the requirement of straddles independent of the timing of requirements reduces the complexity problem.

The objective is to evaluate the straddle layout in a container terminal. This study aims to use a proposed heuristic dispatching rule regardless of the terminal's physical layout and to identify parameters affecting the system performance.

5.6. Performance measures

In most cases the primary operational goal faced by the terminal operators is output. What throughput of containers per unit time can the terminal achieve? A related secondary goal is to control the utilisation of container handling equipment such as straddle carriers and queue lengths obtained. The container terminal operation gives primary importance to achieving throughput goals while utilisation of resources and queue length are used as guidelines to reveal efficiencies and inefficiencies in the terminals. The performance measure is used to test operation parameters in the layout including the number of straddles needed. The simulation modelling uses the following performance measures:

- Total daily throughput
- Average container flow time.
- Straddle utilisation rate.
- Average number of containers waiting in the queues.
- Average number of containers waiting in the queue for service by straddles.

The throughput is defined to be the number of containers completed in a given time period by the system. The container flow time is the sum of the waiting time of an arrival at the truck grids, total travel time determined by the visitation sequences, total loading/unloading times for the stations on the visitation sequences, and total straddle blocking time during the travel on route in the North Park network. The average straddle utilisation can be used to determine the number of straddles needed in the North Park grid. The straddle utilisation is expressed by the sum of the times the straddles are used divided by the total available time.

5.7. Data collection and analysis

The operations of the terminal were observed closely to obtain data for the simulations. The data collection focused on:

(i) ***Interarrival time:*** The interarrival time of trucks carrying export and requesting import containers at North Park grid was observed (see Table 5.1) for a period of 11 days (22^{nd} Feb 99 to 4^{th} March 99). When these data were fitted to a distribution, the most appropriate distribution was found to be lognormal i.e. 1.5 + Lognormal (15.2, 12.8), which shows a minimum interarrival time of 1.5 minutes (see Appendix F).

Table 5.1. Data observed for interarrival time of trucks at North Park grids in minutes.

Identifier	Number of data points	Minimum data value	Maximum data value	Sample Mean	Sample standard deviation
Interarrival time of trucks at grids	651	2	71	16.4	10.8

(ii) ***Number of containers at the North Park grid:*** Statistical analysis of the data indicated that the variations in export and import containers in trucks coming to the terminal are significant. Table 5.2 shows the number of containers (export or/and import) per truck varies between one and six. For this study, the number of containers for pick-up (import) and drop-off (export) at each gird was observed for a period of 11 days (22nd Feb 99 to 4^{th} March 99).

For this variable, the discrete probability distribution is assigned as Discrete (0.758, 1, 0.950, 2, 0.978, 3, 0.993, 4, 0.999, 5, 1.0, 6). This random variable returns a value of 1 (one container) with a probability of 0.758, a value of 2 (two containers) with a probability of 0.192, a value of 3 (three containers) with a probability of 0.028, a value of 4 (four containers) with a probability of 0.015, a value of 5 (five containers) with a probability of 0.006, and a value of 6 (six containers) with a probability of 0.001 (corresponding to a cumulative probability of 1.0). Similarly attribute move type (i.e. export or import) is derived from 14 months (i.e. Jan 98 to Feb 99) of data fitted to a discrete probability distribution. We assigned this value as Discrete (0.49, 1, 1.0, 2) which returns a value of 1 as export with probability 0.49, and a value of 2 as import with probability of 0.51.

Table 5.2. Number of containers on each truck for pick-up and drop-off at North Park grid.

Grid Number	One container	Two containers	Three containers	Four containers	Five containers	Six containers
No. 7	38	11	1	2		
No. 8	36	13	2	1		1
No. 9	45	13	1			
No. 10	48	11	2	1	1	
No. 11	46	13	1			
No. 12	41	10	2	1		
No. 13	48	7	2			
No. 14	36	14		3		
No. 15	42	12	1			
No. 16	45	8	3	1	2	
No. 17	51	7	3	1	1	
No.18	39	11	1			
Total trucks	515	130	19	10	4	1

(iii) *Container visitation sequence*: In a system each export and import container processed through the facility typically has its own storage plan before its final destination (loading into vessel or loading into road vehicles at grid) defining the sequence of operations required to store the container. To determine a particular container's destination, we must know its visitation sequence (i.e. the sequence of storage yard that the container must visit). The analysis of the proportion of import and export container movements to different storage yard areas has been carried out for 6955 containers (3614 export containers and 3341 import containers) corresponding to an operation time (1st to 7th March 99 and 14th to 21st March 99) of a two week period. Results from the above analysis are shown in Tables 5.3 and 5.4.

Table 5.3. Visitation sequence of import containers from yards to truck grid.

Yard block in North Park	Probability of visitation of yard (combined of 1st to 7th and 14th to 21st March 99)
E4 & E3 (L & M rows)	0.565
F4 & F3 (N & X rows)	0.225
D3 (G rows)	0.006
G4 (O & P rows)	0.156
G2 (WX rows)	0.014
H5 (P & Q rows)	-
F5 (H, J, & K rows)	0.025
C3 (D rows)	0.009

Table 5.4. Visitation sequence of export containers from North Park grid to yard.

Yard block in North Park	Probability of visitation of yard (combined of 1st to 7th and 14th to 21st March 99)
E4 & E3 (L & M rows)	0.03
F4 & F3 (N & X rows)	0.14
D3 (G rows)	0.05
G4 (O & P rows)	0.29
G2 (WX rows)	0.01
H5 (P & Q rows)	0.02
F5 (H, J, & K rows)	0.40
C3 (D rows)	0.06

From Table 5.3, we would like to assign the import yard visitation sequence for import containers a randomly selected value of either 1 or 2 or 3 or 4 or 6 or 7 or 8, with a 0.565 chance of the value being a 1 (yards E4 and E3), a 0.006 chance of the value being 2 (Yard D3), a 0.225 chance of the value being 3 (yards F4 and F5), a 0.156 chance of the value being 4 (yard G4), a 0.025 chance of the value being 6 (yard F5), a 0.014 chance of the value being 7 (yard G2), and 0.009 chance of the value being 8 (yard C3). This was accomplished by using the random variable discrete for sampling from a user defined discrete probability distribution. The set of discrete values consists of 1, 2, 3, 4, 6, 7, and 8; and the corresponding cumulative probabilities are 0.565, 0.571, 0.796, 0.952, 0.977, 0.991, and 1.0, respectively. Therefore, the probability distribution function is Discrete (0.565, 1, 0.571, 2, 0.796, 3, 0.952, 4, 0.977, 6, 0.991, 7, 1.0, 8).

Similarly, for export container visitation the sequence shown in Table 5.4 has the probability distribution Discrete (0.03, 1, 0.08, 2, 0.22, 3, 0.51, 4, 0.53, 5, 0.93, 6, 0.94, 7, 1.0, 8). This random variable returns a value of 1 (yards E4 and F5) with a probability of 0.03, a value of 2 (yard D3) with a probability of 0.05, a value of 3 (yards F4 and F3) with a probability of 0.14, a value of 4 (yard G4) with a probability 0.29, a value of 5 (yard H5) with a probability 0.02, a value of 6 (yard F5) with a probability 0.40, a value of 7 (yard G2) with a probability 0.01, and a value of 8 (yard C3) with a probability of 0.06 (corresponding to a cumulative probability of 1.0).

(iv) *Transportation system*: As the straddles are manually operated with computer controlled scheduling, it is likely that a detailed model, which incorporates speed, acceleration, deceleration, and velocity change factor in restricted route and yards, would necessarily give better results. A time study on the drop-off and pick-up of containers by straddles at grids and yard areas was eventually conducted (see Table 5.5). The study indicates that pick-up time is much faster than drop-off time of containers particularly at grids. This could be caused by a difficulty on the part of the straddle driver viewing from the driver's cabin while placing a container on the truck trailer particularly the 40ft size and over-dimension box. The following probability functions are selected irrespective of yard and grid shown in Table 5.6 (see Appendix F for details). However, pick-up time of export containers at truck grids is the same as the pick-up times of import containers from yard blocks. Similarly drop-off time of import containers at truck grids are also the same as drop-off time of export containers at yard blocks. Table 5.7 shows the straddle characteristics. To estimate the acceleration and deceleration of straddles, we have used the following equations [Halliday and Resnick (1988, pp. 12-51)]:

$$\chi_{\delta} - \chi_{\delta_0} = v_{\delta} t_{\delta} - \frac{1}{2} a_{\delta} t_{\delta}^{2} \qquad [5.1]$$

$$v_{\delta}^{2} = v_{\delta_0}^{2} + 2a_{\delta}\left(\chi_{\delta} - \chi_{\delta_0}\right) \qquad [5.2]$$

Equations 5.1 and 5.2 are used to estimate the two operands, acceleration and deceleration, describe the additional time required to start or stop the straddles. Equation 5.1, in which $\chi_{\delta} - \chi_{\delta_0}$ is the displacement of straddle carrier between $t_{\delta} = 0$ and $t_{\delta} = t_{\delta}$, v_{δ} is maximum velocity (m/sec) of a straddle carrier, a_{δ} is the acceleration of a straddle carrier (m/sec^2), and t_δ is the time required by the straddle to reach the final velocity v_δ. A straddle takes an average of 15 seconds (i.e. 13 seconds when empty and 17 seconds when fully loaded) to reach 25 km/hr over a displacement of 50 m. We are assuming that the acceleration is constant. The result is given in Table 5.7. Similarly in Equation 5.2, $v_{\delta 0}$ is the velocity of a straddle carrier (m/sec) at time $t_\delta = 0$. When the straddle driver applies the brakes the vehicle reduces from a velocity of 25 km/hr to 0 km/hr over a displacement of 7 m. Noting that v_δ is zero and solving the equation gives us a negative value for the acceleration which reminds us that the velocity is decreasing (see Table 5.7).

Table 5.5. Data observed for drop-off time/pick-up time of export and import containers in minutes.

Identifier	Number of data points	Minimum data value	Maximum data value	Sample mean	Sample std. dev.
Drop-off time of imports at grids/drop-off time of exports at yards	54	0.2	1.53	0.752	0.306
Pick-up time of exports at grids/pick-up time of imports at yards	54	0.25	1.25	1.25	0.236

Table 5.6. Straddle loading and unloading time in minutes.

Variable	Probability distribution expression
Drop-off time of imports at grids/drop-off time of exports at yards	Triangular (0.06, 0.526, 1.67)
Pick-up time of exports at grids/pick-up time of imports at yards	0.15 minutes + Gamma (0.113, 3.42)

Table 5.7. Straddle carrier characteristics.

Variable	Value
Maximum velocity limit in terminal	5.55 m/sec
Maximum velocity (designed)	6.95 m/sec
Velocity in restricted route and yard area	2.5 m/sec to 3.33 m/sec
Acceleration	0.48 m/sec^2
Deceleration	3.44 m/sec^2

(v) ***Downtimes***: Downtimes due to failures of straddles can be modelled on either calender time or on busy time when data are available (Law, 1990 and Law and Kelton, 1991). The calender time approach models the time between failures based on the elapsed calender time. The busy time approach uses the total accumulated busy time for this purpose. In this study, we mainly used the calender time approach since data available were based on calender time. Down times of straddles are considered under two categories: planned maintenance and break down. However, the straddle availability analysis of the terminal indicates that there is no separate record for maintenance and break down time of straddles and these are grouped under one heading. Moreover the management does not record which straddles are used in North/South Park but record them in the terminal as a whole. Straddles used in landside operations do not work during the night shift (10.00 pm to 5.30 am) and only work continuously during seaside operations. We have used the straddle availability analysis data to estimate break down and time between failures during the day and afternoon shifts of the land interface operation. Failure duration again comprises two parts based on the duration of repair time. If straddles' repair time is less than one hour this is called a short duration repair time. If straddles' repair time is above one hour (between one hour to 15 hours) this is usually designated as long repair time or maintenance time and they are often physically removed for repair to the maintenance section of the engineering department of the terminal. However, management replaces the defunct straddle with an operational one from its pool of reserves. This takes 10 to 15 minutes to replace the straddles that have broken down.

The duration of failures (break down and planned maintenance) and interfailure (time between failure) time distributions were assessed using information extracted from the straddle availability analysis records. For the purpose of selection of distributions, the actual daily data on straddle down times for one and half (1st Feb to 17th March 99) months is used (see Table 5.8 and F.4 of Appendix F). However, both short repair and long repair are not considered for this study, because the management is replacing a new straddle within a short time period from its reserve pool. The following distributions are fitted to the data as shown in Table 5.9. The down time, which is the time it takes to replace straddles, is uniformly distributed between 10 minutes and 15 minutes. When the straddle is repaired, it is either returned to service or kept in the reserve pool ready for the next break down.

Table 5.8. Data observed for straddle failure and repair time in minutes.

Identifier	Number of data points	Minimum data value	Maximum data value	Sample mean	Sample standard deviation
Interfailure time	704	4.8	11436	1272.24	1609.68
Repair time < one hour	165	0.2	60	20.8	14.4
Repair time > one hour	460	61	900	508	292

Table 5.9. Straddle failure time in minutes.

Variable	Probability distribution expression
Time between failure (break down)	4 minutes + Weibull (1.1e+003, 0.717)
Down time (unavailability)	Uniform (10, 15)

5.8. Straddle carrier route layout

The straddle carrier route layout is depicted in Figure 5.6. The route layout shows the direction of travel. The route layout not only allows one-way travel, but also two-way travel. The numbers near the diamonds on the layout identify intersections, and the connections between these intersections are labeled as links. The link comprises the straddle carrier layout. The number of zones and the length of zone together define the travel distances of straddles for a link. Table G.1 of Appendix G show the links' names with beginning and ending intersections, number of zones, length of each zone and total length of link.

Each of the eight storage yards (i.e. G4, H5, F5, E4, G2, D3 and C3) is used to store both export and import containers. Each of the eight yards has a pair of drop-off stations (for export containers) and pick-up stations (for import containers) for container handling purposes (see Figure 5.6). In addition, each of the 12 grids in North Park grid area has a single drop-off station (for import containers) and pick-up station (for export containers). Therefore, all incoming pick-up or drop-off requests from trucks are not separated by grids. All incoming pick-up or drop-off requests are responded to on a first-come, first-served basis in each grid.

The intersections in the network are labelled from 1X to 109X in the Figure 5.5 including pick-up and drop-off stations. Intersections 1X to 12X are associated with stations Grid 7 to Grid 18 for pick-up and drop-off containers from or onto the trucks. Similarly intersections 43X, 50X, 37X, 32X, 108X, 26X, 36X, and 54X are associated with stations such as 1Y (in yard block E4), 2Y (in yard block D3), 3Y (in yard block F4), 4Y (in yard block G4), 5Y (in yard block H5), 6Y (in yard block F5), 7Y (in yard block G2), 8Y (in yard block C3) for drop-off of export containers. Other intersections such as 95X, 92X, 100X, 103X, 29X, 97X, 107X, and 89X are associated with Import1, Import2, Import3, Import4, Import5, Import6, Import7, and Import8 stations for import container pick-up in yard blocks E4, D3, F4, G4, H5, F5, G2, and C3. The straddle will move between these stations when transporting a container. The remaining intersections in the model are used to define the characteristic of the straddle carrier route.

The one exception to one-way travel is the spur link for reaching the truck grid area at intersections 1X, 2X, 3X, 4X, 5X, 6X, 7X, 8X, 9X, 10X, 11X, 12X, 107X, and 36X. Spur travel defines a special case in which the ending intersection of the link is a dead end, i.e. no other links are connected to this intersection in the straddle layout. The spur designation allows the straddle to enter the spur link and travel to ending intersection (1X to 12X), while at the same time preventing another straddle from entering the same spur. Links 1X24X, 2X23X, 3X22X, 4X21X, 5X20X, 6X19X, 7X18X, 8X17X, 9X16X, 10X15X, 11X14X, 13X12X, 106X107X, and 35X36X are considered to be spur links in the model. In the case of spurs, the ending intersection ID is a dead end – not connected to the network by any links other than the spur.

It is a very difficult task to track the straddle movements in each row of the yard blocks in a terminal for drop-off and pick-up of export and import containers. For this complicated system, we used a pair of pick-up and drop-off stations for import and export containers in each of eight yard blocks. Each pick-up and drop-off station is modelled by using the Advanced Server module of ARENA™. This allows one to model a more complex yard system. Temporary blocking can occur in the storage blocks if a straddle is dropping or picking a container at the drop-off and pick-up station in yard blocks and another straddle needs to pass that operation. In this case, the second straddle waits until the first straddle has completed its task and has moved out of the way.

Therefore, the control logic for this storage yard system is intentionally kept fairly simple. The basic goal is to avoid the congestion at pick-up and drop-off stations in yards by straddles coming to the same stations. This completely eliminates the waiting time of straddles to get a row position in yards for pick-up or drop-off containers.

In spurs the straddle keeps control of the entire link to ensure that it can return to the main route intersection. The links connecting pick-up and drop-off stations in yard blocks G4, F5, F4, E4, D3, and C3 are considered to be unidirectional in the model whereas links connecting to yard block G2 are spur links. Similarly the link 46X41X is also considered to be unidirectional in the model. In case of unidirectional links, straddles can only move from the beginning of an intersection to the end of an intersection. Similarly links connecting the pick-up and drop-off stations in yard block H5 are considered in the model as bi-directional links. Bi-directional links allow straddles to move in both directions at intersections on links. Other links shown in Figure 5.6 are straddle routes.

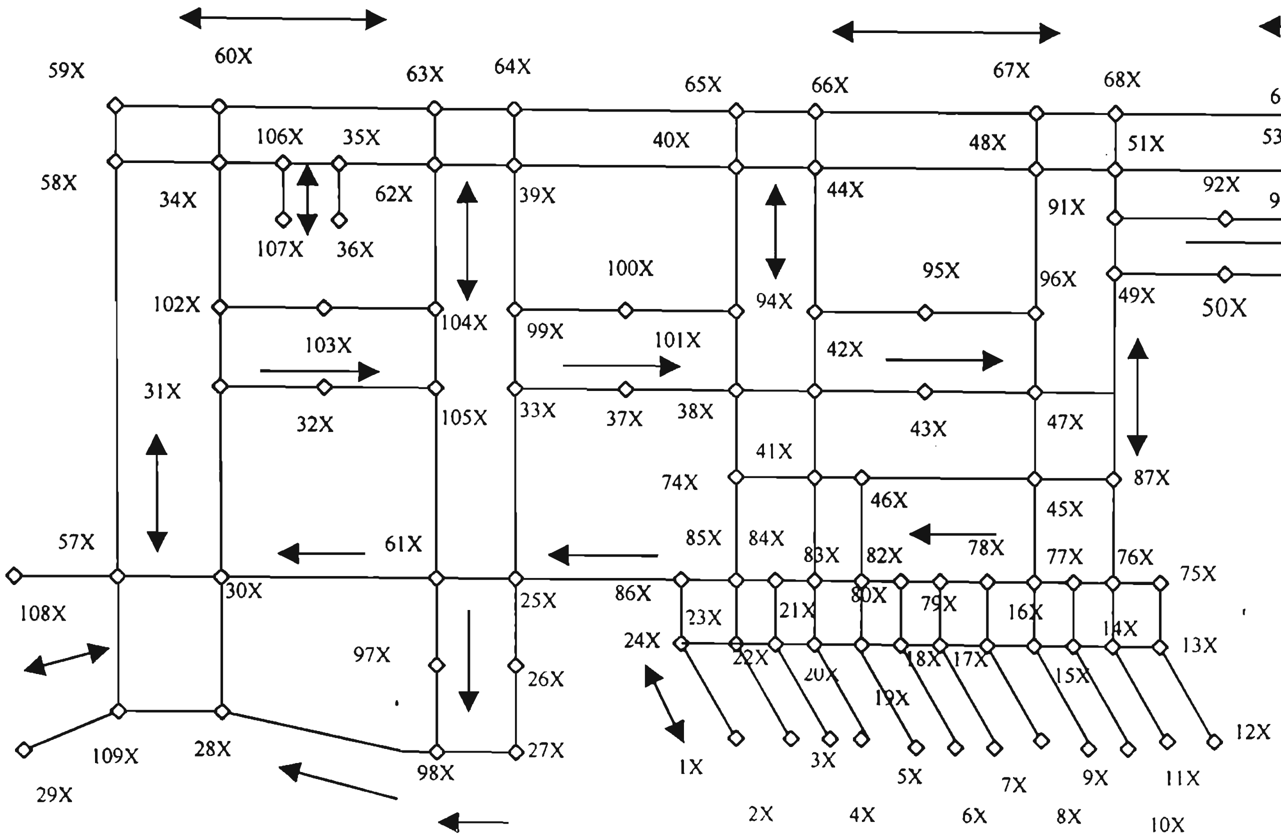
Intersection 46X lies on the route layout, which is used as a straddle staging because of close proximity to the grid area. When a straddle has completed its task and there are no other requests in the truck grids for transport, the straddle is sent to the staging area at intersections 46X to await the next request. If more than one straddle arrives at the staging area, they automatically accumulate along link 45X46X, behind the straddles already there. This simple method of control prevents an idle vehicle from blocking another straddle that is attempting to carry out a transport.

Straddles have acceleration and deceleration values that can significantly affect travel time between positions. Acceleration is always applied whenever a stopped or slowed straddle is returning to a higher speed. Deceleration is applied whenever a straddle anticipates a stop.

It is assumed that the straddle turns a corner on the route at its current velocity without slowing down along the straddle route. The velocity change factor has been defined, on each link, whether the straddle will travel faster or slower through the links than its current velocity, because all straddles travel more slowly in yard blocks, on grids, and areas of high congestion particularly in front of truck grids. The links passing through yard blocks have a velocity change factor of 0.6. This factor is multiplied by the velocity and is used during straddle travel through the link. For example, if a value of 0.6 is entered, then a straddle moving through the link is reduced its speed to 9 km/hr from its current velocity 15 km/hr. The spur links also have velocity change factor of 0.6.

The links close to the grids such as 86X24X, 85X23X, 84X22X, 83X21X, 82X20X, 81X19X, 80X18X, 79X17X, 78X16X, 77X15X, 76X14X, 75X13X, 45X46X, 46X82X, and 46X41X have a similar velocity change factor and all other links in the model remain unchanged.

In the model, the straddles travelling from one point in the system to another use the shortest- distance matrix from all intersections in the route layout to all destinations. The selection of shortest path is based on the current location and destination of straddles. However, a system condition requires that an empty straddle should not pass through the storage yard if there is no job in that yard. This requires a more permanent change to the shortest distance matrix. To overcome this problem, straddles are assigned an alternative route as a bypass in order to prevent any possible waiting because of blocking at intersections as shown in Table G.2 of Appendix G.



Pick-up/drop-off (import and export containers) station (grids): 1X, 2X, 3X, 4X, 5X, 6X, 7X, 8X, 9X, 10X, 11X, and 12X
Dorp-off (export container) station: 26X, 32X, 36X, 37X, 43X, 50X, 54X, and 108X
Pick-up (import container) station: 29X, 89X, 92X, 95X, 97X, 100X, 103X, and 107X
Straddle staging station: 46X
Intersections: The remaining numbers
Zones: Branches between any two adjacent numbers

Figure 5.6. The straddle layout in the North Park of container terminal.

The straddle carrier is unrestricted by space on its designated route. In this study zone control methods are not implemented in order to avoid deadlocks (see Pegden *et al.*, [1995] for comprehensive text on zone control). Therefore, straddles can be assigned a length of zero in order to allow them to pass one another in a two way access route.

5.9. Simulation models

First a basic model was developed using ARENA 3.5 which uses SIMAN V as the simulation language and CINEMA for animation (Kelton *et al.*, 1998 and Arena user's guide with version 3.5, 1998). The model building process is described in Appendix G. The model is used to define the existing straddle carrier layout in the North Park. The following assumptions were made in formulating the model.

- No attempt is made to keep track of what is in the yard area or where the containers are.
- Straddles coming to the rows in the yard blocks for pick-up or drop-off containers have a negligible waiting time.
- Storage yard capacity is the same for both export and import containers.
- The stopping of straddles due to the exchange of drivers in each shift has not been included because this time is negligible.
- Straddles are running continuously in a two shift operating system unless there is a straddle failure.
- It is assumed that the same type of straddles provides the same level of service to trucks.
- All the grids are occupied by trucks on the first-come-first-served basis.
- There are no limits on the queue waiting sizes for service of straddles.

The assumptions used to formulate the model were all closely aligned to the real system. ARENA allows the straddle carrier operation to be animated and the operation of container transport can be visualised. Thirty replications can be run using the Fast-

Forward function in a minimum 3.57 hrs and a maximum of 11.36 hrs on a PC fitted with a 350MHz Pentium® II processor and at least 64-MB memory. The Fast-Forward function gives some of the increased speed of a non-animated simulation run. The animation events are processed during the fast-forward period, but are not displayed on the screen. To run a validated model for simulation experiments quickly the batch run (no animation) option together with Fast-Forward function can be used to save computer time. Thirty replications can be run in a minimum time period of 5.85 minutes to maximum of 21.55 minutes using the Batch Run option together with Fast-Forward function on a PC fitted with 350 MHz Pentium® II processor and at least 64 MB memory. This is the fastest mode of execution as no animation is generated during the simulation run. A schematic of North Park grid and yard blocks as portrayed by ARENA is shown in Figure G.1 of Appendix G.

5.10. Verification and Validation of model

To validate the basic model, several pilot runs were performed. The trace feature of Arena allows a detailed examination of the movements of entities (containers) through the system to make sure that the correct yard station visitation sequences are followed. A number of checks during the verification of the model logic have been performed to ensure that the model is a good representation of reality. During the validation process, minor changes to the model and adjustment of parameter values were made until the validity of the basic model was established. We have compared the output from the basic model to the observed data of the container terminal in Tables 5.10, 5.11, and 5.12.

Table 5.10. Comparison of container flow time with observed data for 6 straddles with the speed being 15 km/hr.

Model results			Real system		
Avg. export container flow time	Avg. import container flow time	Avg. container flow time	Avg. export container flow time	Avg. import container flow time	Avg. container flow time
5.37 min	5.73 min	5.55 min	5.56 min	5.35 min	5.45 min

The export container flow time was observed on 1st March 99 with 379 data points (see Appendix F). Similarly the import flow time in North Park was observed from 1st March 99 to 4th March 99 with the number of data points being 1271. The sample mean of both export and import container flow times was used to compare with model results for validation purposes.

Table 5.11. Comparison of minimum container flow time with observed data with 6 straddles and maintaining a speed of 15 km/hr.

Model results			Real system		
Avg. min. export container flow time	Avg. min. import container flow time	Avg. min. container flow time	Export min. container flow time	Import min. container flow time	Avg. min. container flow time
2.11 min	2.63 min	2.37 min	1.00 min	1.00 min	1.00 min

Construction of confidence interval estimates for the expected values of model parameters is used to reveal whether we need more observations by increasing a number of replications in the simulation run. We have high confidence that the expected export container flow time is between 5.32 minutes and 5.41 minutes which is within about 5% of the point measurement of this value.

Table 5.12. Comparison of maximum container flow time with observed data with 6 straddles and the speed is 15 km/hr.

Model results			Real system		
Avg. max. export container flow time	Avg. max. import container flow time	Avg. max. container flow time	Max. export container flow time	Max. import container flow time	Avg. max. container flow time
15.77 min	15.49 min	15.63 min	17.00 min	15.00 min	16.00 min

Similarly we can state with high confidence (0.95) that the true expected import container flow time for this basic model is between 5.68 minutes and 5.77 minutes. Applying the calculation of an approximate 0.95 confidence interval for other model parameters yields the following result (see Table 5.13). From Table 5.13 it is concluded that parameters of particular interest in this model produced a small half-width.

Table 5.13. Confidence intervals (CI) summary.

Identifier	Avg.	0.950 CI half-width	Minimum value	Maximum value	Number of replications
Min. import container flow time	2.63 minutes	0.03900	2.3365 minutes	2.8321 minutes	30
Max. import container flow time	15.49 minutes	0.80076	12.13 minutes	20.71 minutes	30
Min. export container flow time	2.11 minutes	0.02984	1.9675 minutes	2.2819 minutes	30
Max. export container flow time	15.77 minutes	0.91499	11.23 minutes	20.69 minutes	30
Avg. throughput export container	424	7.58	380	463	30
Avg. throughput import container	432	8.39	383	476	30
Avg. straddle utilisation	85.08 %	1.0299	78.605 %	88.941 %	30
Avg. export container per hr	28.248	0.50576	25.33	30.866	30
Avg. import container per hr	28.82	0.55969	25.53	31.73	30

Therefore in this model we do not require an additional number of replications to achieve adequate precision. For further validation of this basic model we have compared the waiting time of jobs (pick-up or drop-off requests) for the service of straddles in grids with the real system in Table 5.14.

Table 5.14. Comparison of average waiting time of trucks and jobs in queue for service of straddles.

Model result		Real system	
Avg. waiting time of trucks in grids	Avg. waiting time of jobs	Avg. waiting time of trucks in grids	Avg. waiting time of jobs
16.58 min	22.965 min	15.6 min	21.606 min

The waiting times of trucks in grids for service of straddles were observed from 11^{th} Aug 98 to 26^{th} Aug 98 for 878 data points with a sample mean of 15.6 minutes. Table 5.15

shows the comparison of throughput (twenty-foot equivalent unit) daily between model result and real system.

Table 5.15. Comparison of total throughput between model result and real system.

Model result	Real system
Average total throughput	Average total throughput
856	785

The comparison of model results with real system data in most cases appears to match favourably. We ensured that the model developed is representative of the actual system.

5.11. Simulation experiments

In order to verify and to ensure better accuracy of the simulation results, several system parameters were changed in the simulation experiments. Four factors which may affect the system performance were identified: the interarrival time of trucks at grids, straddle speeds, number of straddles, and straddle job assignment heuristic rule by the trucks at grids. This interarrival time (time between truck arrivals on grids) can be increasing by 50% and decreasing by 50% from the present rate. The increase of time between arrival of tucks decreases the number of trucks in the model. Similarly decrease of time between arrival of trucks increases the number of trucks in the model. This demonstrates that a 10% decrease in interarrival time is the same as a 10% increase in arrival rate of trucks in the model and vice versa. The heuristic rule used to assign jobs to straddles is also an influential factor in container handling performance. The current heuristic job assignment rule at the truck grids is the preferred order rule (POR) which always selects the available straddle with the lowest number irrespective of its position from the job request grid (as discussed in section 5.3). The impact of heuristic job assignment rule based on the smallest distance from station (SDS) is included in the experiment to estimate the system performance, because the management has a proposal to implement such a job assignment rule in the near future. The parameters and their settings in the simulation are described below:

1. Interarrival time of trucks – seven levels.
   a. at present rate
   b. 10% increase
   c. 30% increase
   d. 50% increase
   e. 10% decrease
   f. 30% decrease
   g. 50% decrease
2. Straddle travel speed – one level.
   a. 15 km/hr
3. Number of straddles – five levels.
   a. 4 straddles
   b. 5 straddles
   c. 6 straddles
   d. 7 straddles
   e. 8 straddles
4. Job assignment rules at the truck grid by trucks – two levels.
   a. preferred order rule (POR)
   b. smallest distance from station (SDS)

Given a basic simulation model, the factors were tested at $7\times1\times5\times2$ factorial design with 70 experiments. Each simulation in our experiment was run for 900 minutes, simulating a 15-hour operation time. Therefore, each experiment was replicated 30 times. The total number of simulation experiments performed is 70 (experiments) $\times$ 30 (replications) which is 2100.

5.12. Analysis of results from simulation experiments

Comparison of average container flow time (defined in section 5.6) using various numbers of straddles with the present straddle selection strategy and proposed heuristic selection rule holding the average speed at 15 km/hr are presented in Figures 5.7 and 5.8.

Using the present selection strategy (see Figure 5.7) a 10% increase in arrival rate of trucks increases the average container flow time from the present 5.55 minutes to 6.88 minutes with 6 straddles.

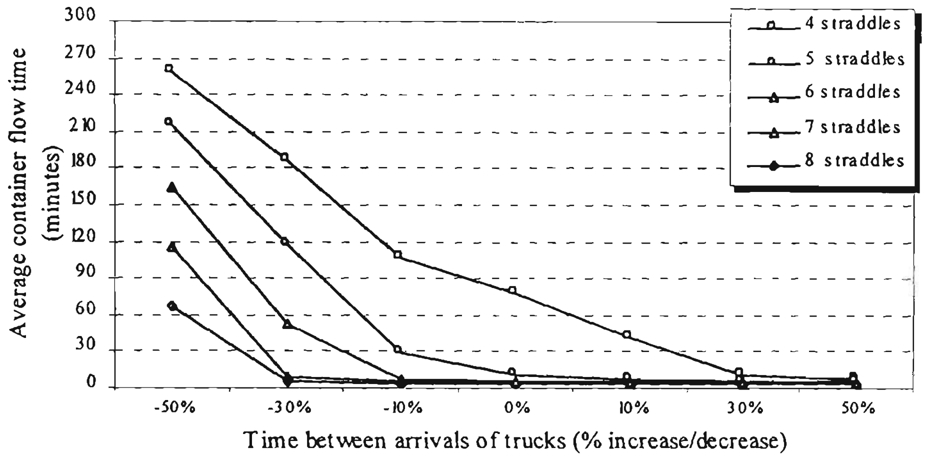


Figure 5.7. Comparison of average container flow time for a range of straddles with the POR heuristic rule (present strategy) maintaining a speed of 15 km/hr.

However, increasing the number of straddles from the present 6 to 7, the average container flow time decreases from 5.55 minutes to 4.63 minutes with the present arrival rate. The same figure shows that with a 10% increase in arrival of trucks compared with the present rate, the container flow time decreases to 5.04 minutes using 7 straddles. Further examination reveals that increasing the arrival of trucks from 10% to 50% (by decreasing interarrival time from 10% to 50%), the average container flow time steadily increases with an increase in the number of straddles from 6 to 8.

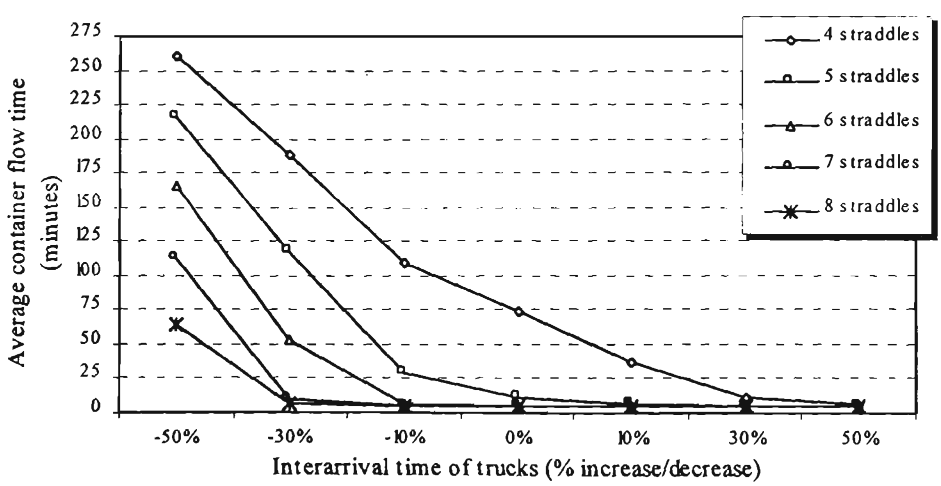


Figure 5.8. Comparison of the average flow time of containers for a number of straddles with SDS selection rule (proposed strategy) with the speed being 15 km/hr.

The proposed straddle selection heuristic rule by trucks shows a similar trend with the present selection strategy in terms of average container flow time (see Figure 5.8).

Comparison of daily throughput using the present selection strategy and proposed selection heuristic rule maintaining an average speed of 15 km/hr with various numbers of straddles is depicted in figures 5.9 and 5.10. Figure 5.9 shows, an increase in the number of straddles from 6 to 7 in the present set-up improves the daily throughput by an average of 13 containers; however a further increase in the number of straddles results in no further increase in the average daily throughput. A 10% increase in the arrival rate of trucks (by 10% decrease in interarrival time) improves the daily throughput in the present set-up by 101 containers with the average container flow time raised from 5.55 minutes to 6.88 minutes.

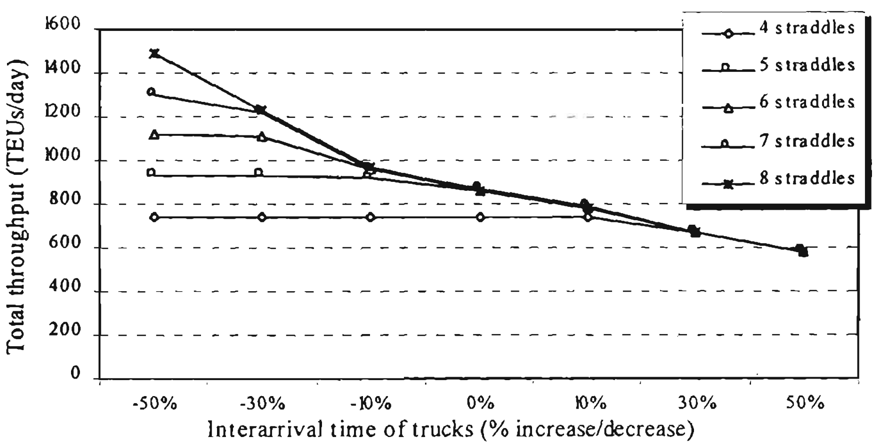


Figure 5.9. Comparison of average total throughput for range of straddles with POR selection rule (present strategy) holding speed at 15 km/hr.

However, an increase in the number of straddles from 6 to 7 and an increase in the arrival rate of trucks of 10% shows that daily throughput does not improve at all. A further increase of straddles from 7 to 8 at a 10% increase in the arrival rate of trucks shows a marginal increase of daily throughput by 10 containers with an average container flow time of 4.44 minutes. As can be seen in Figure 5.10, the average daily throughput for the proposed heuristic selection rule is the same as compared to the present selection rule with an average flow time of 5.59 minutes under the present set-up.

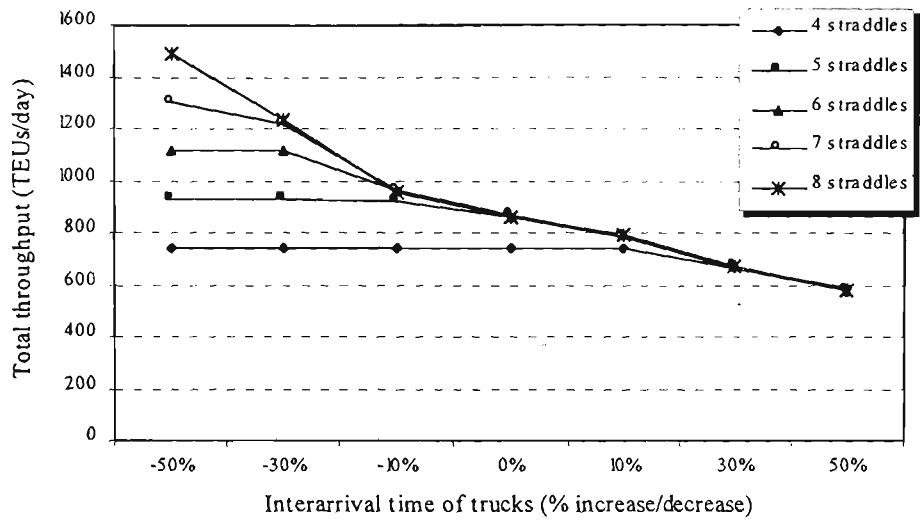


Figure 5.10. Comparison of average total throughput for range of straddles with SDS selection rule. The speed is 15 km/hr.

Increasing the number of straddles from 6 to 7 in the present set-up improves daily throughput by an average of 13 containers only. Any further increase of straddles with the present set-up results in a steady decrease in daily throughput. The results indicated that the POR rule and the SDS rule performed equally well on average container flow time and daily throughput.

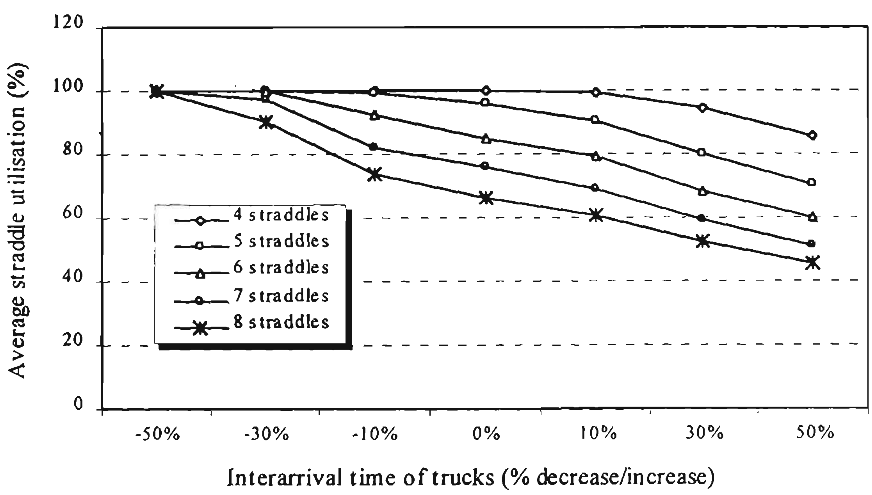


Figure 5.11. Comparison of average straddle utilisation for range of straddles with POR selection rule when holding the speed at 15 km/hr.

A comparison of the straddle utilisation under the present straddle selection strategy and the proposed selection heuristic rule under the present set-up is provided in Figures 5.11 and 5.12 when holding the average speed at 15 km/hr. In the same figure, it can be seen that if there is an increase of straddles from 6 to 8 then utilisation decreases from 85 percent to around 66 percent for both rules with the present arrival rate. However, the use of a smaller number of straddles causes higher straddle utilisation under both heuristic rules.

The straddle utilisation under the present set-up suggests a system close to optimal capacity. The results from the simulation indicated that both heuristic rules performed equally well on straddle utilisation.

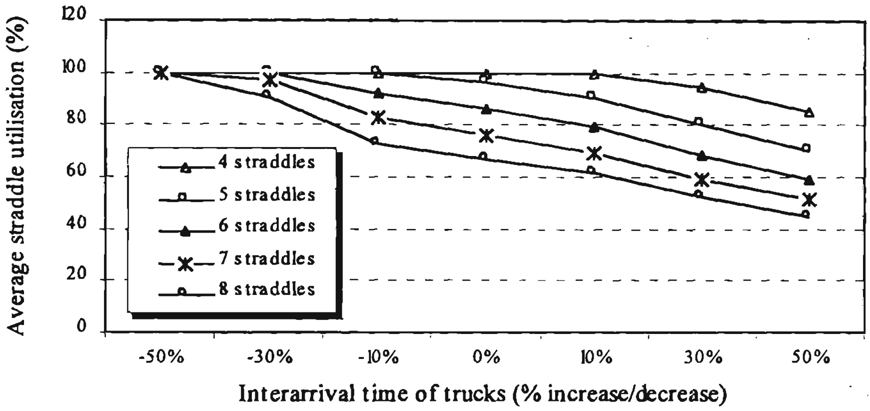


Figure 5.12. Comparison of average straddle utilisation for range of straddles with SDS selection rule holding speed at 15 km/hr.

A comparison of the average waiting time of jobs in the queues for service by straddles using the present selection strategy and proposed heuristic selection rule is provided in Figures 5.13 and 5.14.

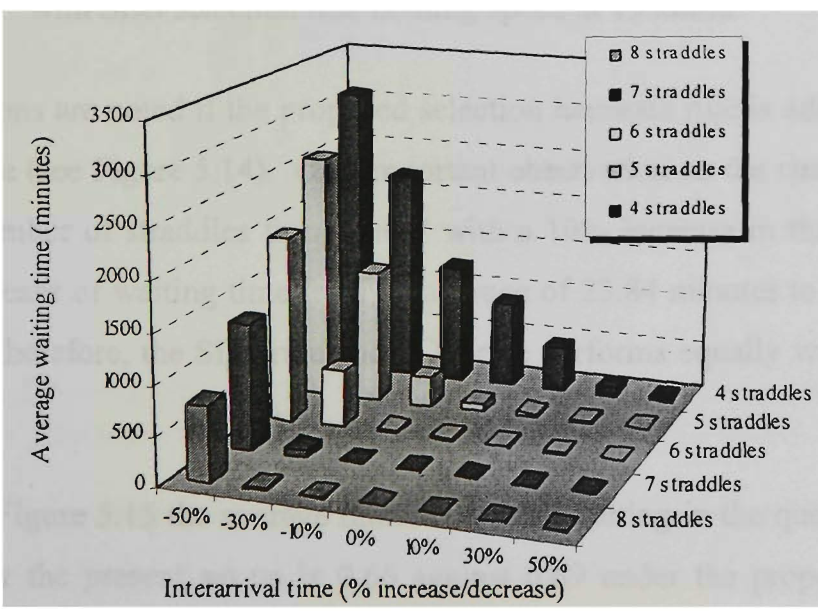


Figure 5.13. Comparison of average waiting time of jobs in the queue for service by straddles with POR selection rule maintaining the speed at 15 km/hr.

In the present set-up an increase in the number of straddles from 6 to 7 decreases waiting time of jobs from an average of 22.96 minutes (equivalent to an average 16.58 minutes of truck waiting time on grids) to 12.29 minutes (equivalent to an average of 8.87 minutes of truck waiting time on grids), a decrease of 46.5%. It is also observed that when the number of straddles increases from 7 to 8, the average waiting time decreases from an average of 12.29 minutes to an average of 7.75 minutes. An increase of 10% of trucks in the present set-up with 7 straddles causes a decrease of the average waiting time to 17.06 minutes from 22.96 minutes at the present arrival rate.

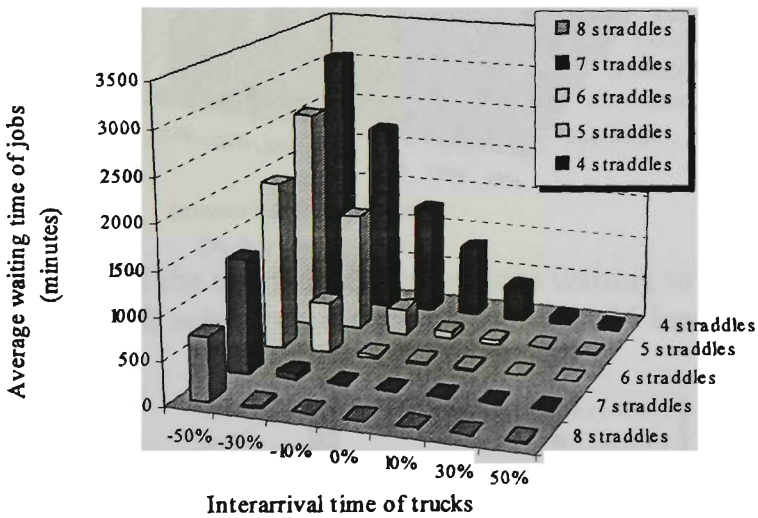


Figure 5.14. Comparison of average waiting time of jobs in queue for service of straddles with SDS selection rule holding speed at 15 km/hr.

Similar observations are noted if the proposed selection heuristic rule is adopted with the present arrival rate (see Figure 5.14). One important observation on the simulation is that increasing the number of straddles from 6 to 7 with a 10% increase in the truck arrival rate causes a decrease of waiting time from an average of 23.84 minutes to an average of 18.88 minutes. Therefore, the SDS rule and POR rule performs equally well on average waiting time.

As shown in the Figure 5.15 the average number of jobs waiting in the queue for service of straddles under the present set-up is 0.66 against 0.69 under the proposed selection heuristic rule (see Figure 5.16). However, an increase of 10% of trucks (decrease of 10% in time between arrival of trucks) with an increase in straddles from 6 to 7 shows that the average number of jobs in the queue is around 1.38 using the POR rule against 0.49 with the proposed SDS rule. With an increase of straddles from 6 to 7 under the POR rule with a 10% increase in arrival rate, the average number of jobs waiting does not change from 1.38.

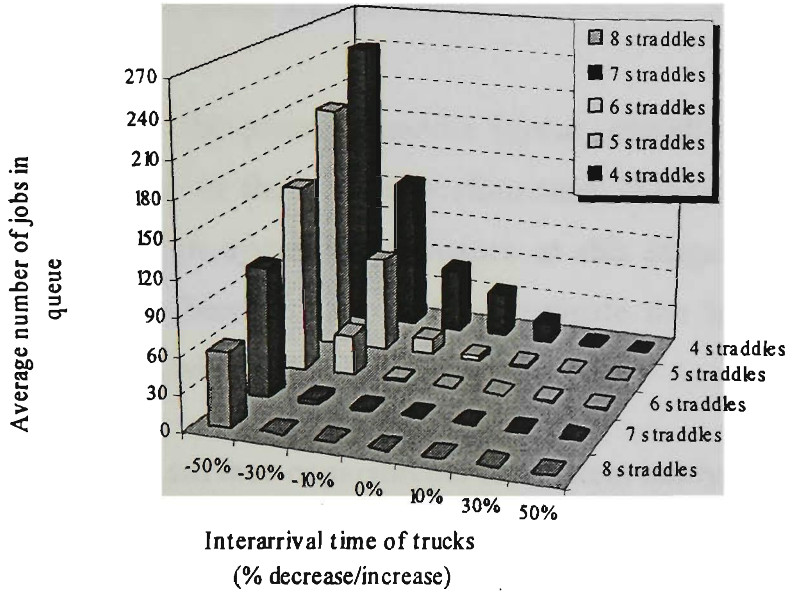


Figure 5.15. Comparison of the average number of jobs waiting to be served by straddles with POR selection rule holding speed at 15 km/hr.

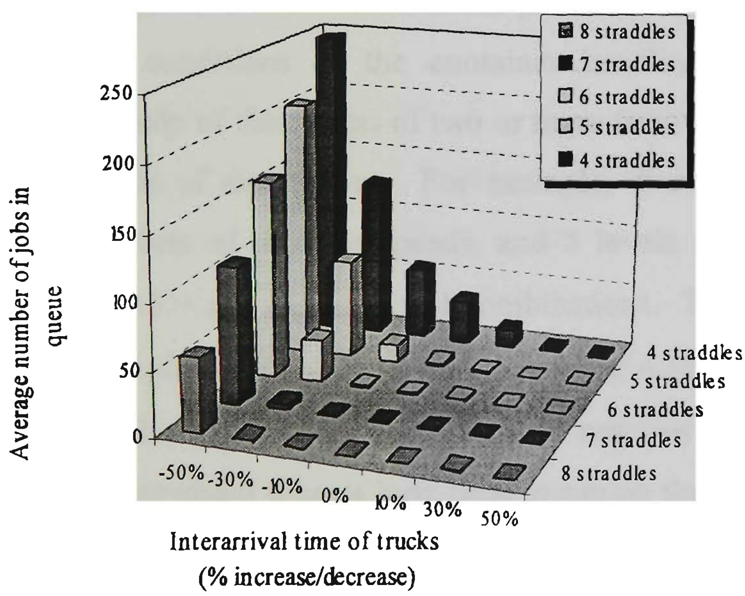


Figure 5.16. Comparison of the average number of jobs waiting to be served by straddles with proposed SDS selection rule holding speed at 15 km/hr.

Figure 5.16 shows the average number of jobs waiting is 1.51 using the SDS rule with the present set-up (6 straddles) against 1.38 jobs if the POR rule were implemented with a 10% increase in the arrival rate of trucks. In the present set-up, the SDS rule performs well on the average number of jobs waiting with a 10% increase in arrival rate.

Overall the SDS rule with the present set-up can not be considered as the best proposed strategy, when both the throughput, low waiting time of jobs, straddle utilisation, and a lesser number of jobs in the queue are considered.

It can be concluded that the present straddle layout, straddle speed and number of straddles is very sensitive to the system performance changes. Since the effect of different straddle speeds on system performance at this stage is unknown, response surface experiments have been performed to investigate the impact of speed on the system performance. This will be discussed in section 5.13.

5.13. Designing response surface experiments for system analysis

In order to gain a better understanding of the effect of different straddle speeds on the container handling system we would prefer a model that actually described mathematically the principal factors involved in the process. The model can be used to suggest better operating conditions of the container handling system. In general experiments involve the study of the effects of two or more factors. Factorial designs are most efficient for this type of experiment. For example, if there are 5 levels of the number of straddles, 5 levels of straddle speeds, and 5 levels of interarrival times of trucks, then there are 5×5×5 = 125 experimental combinations. This implies that if each of the combinations are replicated 30 times, then a total of 125×30 = 3750 simulation runs would be needed. 125 experimental combinations requires considerable hard disk space for storing output files and it takes a long time to run on the computer. In order to avoid 125 treatment combinations, we can run a small number of runs by using a design that contains close to the minimal number of runs in order to approximate the response of interest.

Response surface methodology is used in the study for exploring the relationships between a number of measured responses from the simulation such as average container flow time, total throughput, average waiting time of jobs in the queue for service of straddles, average number of job requests in the truck grid, and average straddle utilisation, and a number of input variables such as the interarrival time of trucks, the number of straddles, and the straddle speed. The objective is to find the relationship between a number of input variables and output variables from the simulation.

We represented the specific response directly by a second-order polynomial approximation expression (Box and Draper, 1987). The second-order model provides a powerful basis for selecting optimal settings for our system. Experimental design plays a crucial role in the performance of the resulting model. The most commonly used design to estimate the second-order model is the central composite design which has been used in this study [Vining (1998, pp. 405-446)]. Such a design consists of a two-level factorial or fractional factorial augmented with further points, which allows the fitting of a second-order model

$$y = \omega_0 + \sum_{i=1}^{g} \omega_i x_{ui} + \sum_{i=1}^{g-1} \sum_{j=i+1}^{g} \omega_{ij} x_{ui} x_{uj} + \varepsilon \qquad [5.3]$$

where x_{ui} is a coded variable that represents the input variable, ω 's are regression coefficients, and ε is a random error. In the simulation experiment input variables range between a lower level and an upper level; that is, the simulation model is not valid outside the range. The central composite design consists of cube points, star points, and centre points (Draper, 1982). A 2^3 factorial was run using the pairs of levels shown in Table 5.16. The input variables are represented through convenient coding. The lower and upper levels were coded as x_{u1}, x_{u2}, and x_{u3}, taking the levels −1 for the lower level and +1 for the upper level (see Table 5.16).

Table 5.16. Coded and uncoded levels of three input variables.

Input variables, δ_i	Coded levels, x_{ui}		Midlevel	Semirange
	-1	+1		
Interarrival time, δ_1	-30.0 %	+30.0 %	0	30.0%
Straddle speed, δ_2	12	18	15	3
Number of straddles, δ_3	5	7	6	1

The actual design used is given in Table 5.18 and Table 5.19, together with the experimental results for POR and SDS selection rules. As seen in these tables, the experimental points consists of cube points, star points, and centre points arranged along the axes of the variables and symmetrically positioned with respect to the factorial cube. The first eight treatment combinations form a 2^3 factorial design (cube points). The next six treatment combinations are the axial runs (star points). The last four treatment combinations represent the centre runs (centre points). A diagram of the central composite design is given in Figure 5.17 while the coded design is given below.

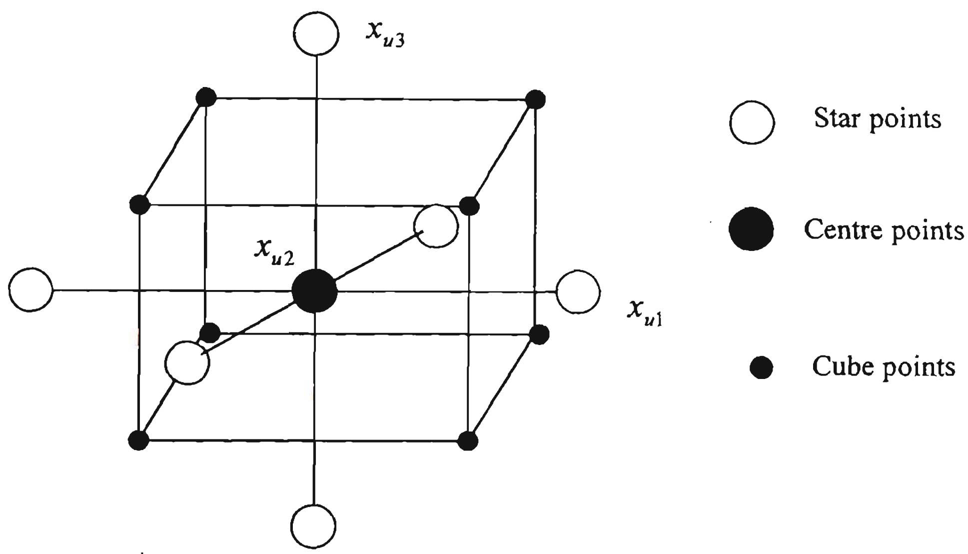


Figure 5.17. A three factor central composite design.

The structure of the central composite design and the relationship between the input variables, δ_1, δ_2, and δ_3, and the coded variables is given by the following equations:

$$x_{u1} = (\delta_1 - 0)/30 \qquad [5.4]$$

$$x_{u2} = (\delta_2 - 15)/3 \qquad [5.5]$$

$$x_{u3} = (\delta_3 - 6)/1 \qquad [5.6]$$

Here 0, 15, and 6 are the mid points of the factors respectively while 30, 3, and 1 are half the ranges of the factors for the cube points. This coding will produce the ± 1 notation for the levels of coded variables. Table 5.17 gives the central composite design matrix in the design variables. Each row in the matrix stipulates the settings of low (-) and high (+) levels of three factors x_{u1}, x_{u2}, and x_{u3}.

Table 5.17. A three-factor central composite design matrix.

	x_{u1}	x_{u2}	x_{u3}	Remarks
Cube Points	-1	-1	-1	Note that the range for the star points for x_{u3} was slightly larger than for x_{u1} and x_{u2} since then straddle number could only take whole number values.
	+1	-1	-1	
	-1	+1	-1	
	+1	+1	-1	
	-1	-1	+1	
	+1	-1	+1	
	-1	+1	+1	
	+1	+1	+1	
Star points	-5/3	0	0	
	+5/3	0	0	
	0	-5/3	0	
	0	+5/3	0	
	0	0	-2	
	0	0	+2	
Centre Points	0	0	0	
	0	0	0	
	0	0	0	
	0	0	0	

For each of the responses we fitted a second order Taylor series approximation of the form

$$y = \omega_0 + \omega_1 x_{u1} + \omega_2 x_{u2} + \omega_3 x_{u3} + \omega_{11} x_{u1}^2 + \omega_{22} x_{u2}^2 \\ + \omega_{33} x_{u3}^2 + \omega_{12} x_{u1} x_{u2} + \omega_{13} x_{u1} x_{u3} + \omega_{23} x_{u2} x_{u3} + \varepsilon \qquad [5.7]$$

where y is the response, the ω 's are parameters whose values are to be determined, x_{u1} is a coded variable that represents the interarrival time of trucks (δ_1), x_{u2} is a coded variable that represents the straddle speed (δ_2), x_{u3} is a coded variable that represents the number of straddles (δ_3), and ε is a random error term.

Table 5.18. Results from the simulation experiment runs based on straddle selection rule POR.

Runs		Uncoded levels			Responses				
		Interarrival time of trucks (% increase or decrease)	Straddle speed (km/hr)	Number of straddles	Average container flow time (minutes)	Average total throughput (TEUs/day)	Average straddle busy (%)	Average waiting time of jobs in queue for service of straddle (minutes)	Average number of jobs in queue
1	Cube points	-30.00	12	5	168.00	789	99.73	1971.73	111.81
2		+30.00	12	5	7.89	656	89.87	44.0625	1.086
3		-30.00	18	5	75.87	1045	99.69	871.8375	49.145
4		+30.00	18	5	4.46	670	71.93	14.45	0.3015
5		-30.00	12	7	49.65	1110	99.8	544.24	30.307
6		+30.00	12	7	5.14	658	68.13	12.046	0.181
7		-30.00	18	7	5.21	1209	89.4	22.885	0.981
8		+30.00	18	7	3.74	669	52.46	6.1885	0.0725
9	Star points	-50.00	15	6	164.20	1116	99.77	1930.265	152.485
10		+50.00	15	6	4.4	582	59.82	9.277	0.13
11		0.00	10	6	35.20	820	99.54	363.395	14.285
12		0.00	20	6	3.99	858	72.15	10.9725	0.27
13		0.00	15	4	78.4	740	99.74	898.395	35.88
14		0.00	15	8	4.259	865	66.66	8.145	0.1375
15	Centre points	0.00	15	6	5.55	856	85.08	22.965	0.662
16		0.00	15	6	5.57	856	85.44	23.225	0.683
17		0.00	15	6	5.54	863	85.27	23.135	0.6805
18		0.00	15	6	5.61	864	85.29	23.67	0.7005

Table 5.19. Results from the simulation experiment runs based on straddle selection rule SDS.

Runs		Uncoded levels			Responses				
		Interarrival time of trucks (% increase or decrease)	Straddle speed (km/hr)	Number of straddles	Average container flow time (minutes)	Average total throughput (TEUs/day)	Average straddle busy (%)	Average waiting time of jobs in queue for service of straddle (minutes)	Average number of jobs in queue
1	Cube points	-30.00	12	5	170.4	790	99.79	2000.9	113.43
2		+30.00	12	5	8.905	673	91.18	55.75	1.4725
3		-30.00	18	5	74.885	1042	99.707	860.215	48.19
4		+30.00	18	5	4.47	671	72.18	14.4975	0.308
5		-30.00	12	7	48.145	1109	99.77	526.9815	29.57
6		+30.00	12	7	5.145	669	69.25	12.1635	0.187
7		-30.00	18	7	5.415	1222	90.22	25.28	1.11
8		+30.00	18	7	3.74	676	53.036	6.151	0.0725
9	Star points	-50.00	15	6	165.38	1115	99.78	1945.76	155.785
10		+50.00	15	6	4.32	577	59.45	9.317	0.104
11		0.00	10	6	32.394	816	99.57	329.355	12.7245
12		0.00	20	6	3.985	864	72.62	10.99	0.27
13		0.00	15	4	73.935	741	99.67	845.26	33.625
14		0.00	15	8	4.229	861	66.39	7.755	0.123
15	Centre points	0.00	15	6	5.55	856	85.08	22.97	0.662
16		0.00	15	6	5.62	861	85.46	23.695	0.6935
17		0.00	15	6	5.555	863	85.27	23.06	0.6805
18		0.00	15	6	5.585	864	85.26	23.395	0.693

The coded variables x_{u1} x_{u2} and x_{u3} are defined on a coded scale from -1 to $+1$ (although the star points go outside this range) and $x_{u1}x_{u2}$, $x_{u1}x_{u3}$, and $x_{u2}x_{u3}$ represent the interactions between x_{u1} and x_{u2}, x_{u1} and x_{u3}, and x_{u2} and x_{u3} respectively. The statistical data analysis package S-Plus was used to calculate the coefficients of the second degree polynomial equation (S + DOX™ User's Manual, 1994). The least squares method is used to derive these coefficients (see Montgomery, 1997). The details of these coefficients and goodness of fit of the model are provided in Appendix H. We have obtained five fitted equations for the POR selection rule of straddles:

$$\begin{aligned}\hat{y}_1 = {} & 1.7129 - 1.0714\,x_{u1} - 0.5581\,x_{u2} - 0.6454\,x_{u3} + 0.5315\,x_{u1}^2 + 0.2368\,x_{u2}^2 + 0.2804\,x_{u3}^2 \\ & + 0.2703\,x_{u1}x_{u2} + 0.4118\,x_{u1}x_{u3} - 0.1507\,x_{u2}x_{u3}\end{aligned} \tag{5.8}$$

$$\begin{aligned}\hat{y}_2 = {} & 862.4348 - 176.3115\,x_{u1} + 32.7049\,x_{u2} + 46.0000\,x_{u3} - 1.0798\,x_{u1}^2 - 4.6798\,x_{u2}^2 \\ & - 13.1720\,x_{u3}^2 - 41.2500\,x_{u1}x_{u2} - 60.5000\,x_{u1}x_{u3} - 20.0000\,x_{u2}x_{u3}\end{aligned} \tag{5.9}$$

$$\begin{aligned}\hat{y}_3 = {} & 1.7511 - 1.8815x_{u1} - 0.9957x_{u2} - 1.0075x_{u3} + 0.4923x_{u1}^2 + 0.4668x_{u2}^2 + 0.3723x_{u3}^2 \\ & + 0.2895x_{u1}x_{u2} + 0.1343x_{u1}x_{u3} - 0.4201x_{u2}x_{u3}\end{aligned} \tag{5.10}$$

$$\begin{aligned}\hat{y}_4 = {} & 3.1425 - 1.6167x_{u1} - 0.8557x_{u2} - 1.0299x_{u3} + 0.5992x_{u1}^2 + 0.3288x_{u2}^2 + 0.3111x_{u3}^2 \\ & + 0.2755x_{u1}x_{u2} + 0.3478x_{u1}x_{u3} - 0.2380x_{u2}x_{u3}\end{aligned} \tag{5.11}$$

$$\begin{aligned}\hat{y}_5 = {} & -0.3876 - 2.1565\,x_{u1} - 0.9637\,x_{u2} + 1.2228\,x_{u3} + 0.6433\,x_{u1}^2 + 0.3487\,x_{u2}^2 + 0.2801\,x_{u3}^3 \\ & + 0.2570\,x_{u1}x_{u2} + 0.2503\,x_{u1}x_{u3} - 0.2802\,x_{u2}x_{u3}\end{aligned} \tag{5.12}$$

where $\hat{y}_1$ denotes the predicted values of average container flow time on a logarithm scale, $\hat{y}_2$ denotes the predicted values of total throughput on a linear scale, $\hat{y}_3$ denotes the predicted values of straddle utilisation in a logistic i.e. $\left[\ln\left(\frac{\text{Straddle Busy \%}}{100 - \text{Straddle Busy \%}}\right)\right]$ scale, $\hat{y}_4$ denotes the predicted values of average waiting time of job in a logarithm scale, and $\hat{y}_5$ denotes the predicted values of average number of jobs in a logarithm scale in any given time in queue for service of straddles for a given values of x_{u1}, x_{u2}, and x_{u3}. The log and logistic transformation were used to improve the accuracy of the second-order model. Because of the wide range of variation of the average container flow time, the average waiting time, and the average number of jobs in the queue, it is more natural to consider an analysis in terms of $y = \ln Y$ of the observed data Y so that the choice of transformation was important. In particular the logistic equation constrains the fitted value to behave between 0% and 100% as desired (for straddle utilisation). Similarly for SDS allocation rule we obtained five fitted equations:

$$\hat{y}_6 = 1.7156 - 1.0661x_{u1} - 0.5539x_{u2} - 0.6463x_{u3} + 0.5380x_{u1}^2 + 0.2301x_{u2}^2 + 0.2761x_{u3}^2 + 0.2499x_{u1}x_{u2} + 0.3955x_{u1}x_{u3} - 0.1241x_{u2}x_{u3} \quad [5.13]$$

$$\hat{y}_7 = 861.6150 - 174.8852\,x_{u1} + 33.1967\,x_{u2} + 46.2500\,x_{u3} - 0.3074\,x_{u1}^2 - 2.4674\,x_{u2}^2 - 12.5911\,x_{u3}^2 - 45.000\,x_{u1}x_{u2} - 62.2500\,x_{u1}x_{u3} - 16.2500\,x_{u2}x_{u3} \quad [5.14]$$

$$\hat{y}_8 = 1.7528 - 1.8902x_{u1} - 1.0111x_{u2} - 1.0072x_{u3} + 0.5133x_{u1}^2 + 0.4990x_{u2}^2 + 0.3483x_{u3}^2 - 0.0634x_{u1}x_{u2} - 0.0661x_{u1}x_{u3} - 0.4929x_{u2}x_{u3} \quad [5.15]$$

$$\hat{y}_9 = 3.1458 - 1.6093x_{u1} - 0.8589x_{u2} - 1.0349x_{u3} + 0.6174x_{u1}^2 + 0.3274x_{u2}^2 + 0.3048x_{u3}^2 + 0.2398x_{u1}x_{u2} + 0.3019x_{u1}x_{u3} - 0.1992x_{u2}x_{u3} \quad [5.16]$$

$$\hat{y}_{10} = -0.3899 - 2.0096x_{u1} - 0.8069x_{u2} - 1.1071x_{u3} + 0.5782x_{u1}^2 + 0.2990x_{u2}^2 + 0.2443x_{u3}^2 - 0.0634x_{u1}x_{u2} - 0.0661x_{u1}x_{u3} - 0.4929x_{u2}x_{u3} \quad [5.17]$$

These response surfaces can be used to predict the average container flow time, total throughput, straddle utilisation, average waiting time in the queue for service by straddles, and the average number of jobs in the queue at various values of interarrival time and number of straddles at various straddle speeds.

5.14. Examination of the fitted surfaces

Figure 5.18 represents contour plots of the surface generated by Equation 5.8 using the present selection strategy. Examination of the response surface reveals that at a speed of 10 Km/hr, the average container flow time raises steadily with increase in arrival rate of trucks when there are fewer than six straddles. Further examination of the plots reveals that at speed of 16 km/hr, the 7-straddle system could decrease the flow time to around 4 minutes with a 10% increase in the number of trucks (10% decrease in interarrival time). At a speed of 18 km/hr it is possible to obtain an average container flow time of 3 minutes if there is a 10% increase in arrival rate by seven straddles. The average container flow time can be further reduced to less than 3 minutes when the speed increases from 18 km/hr to 20 km/hr.

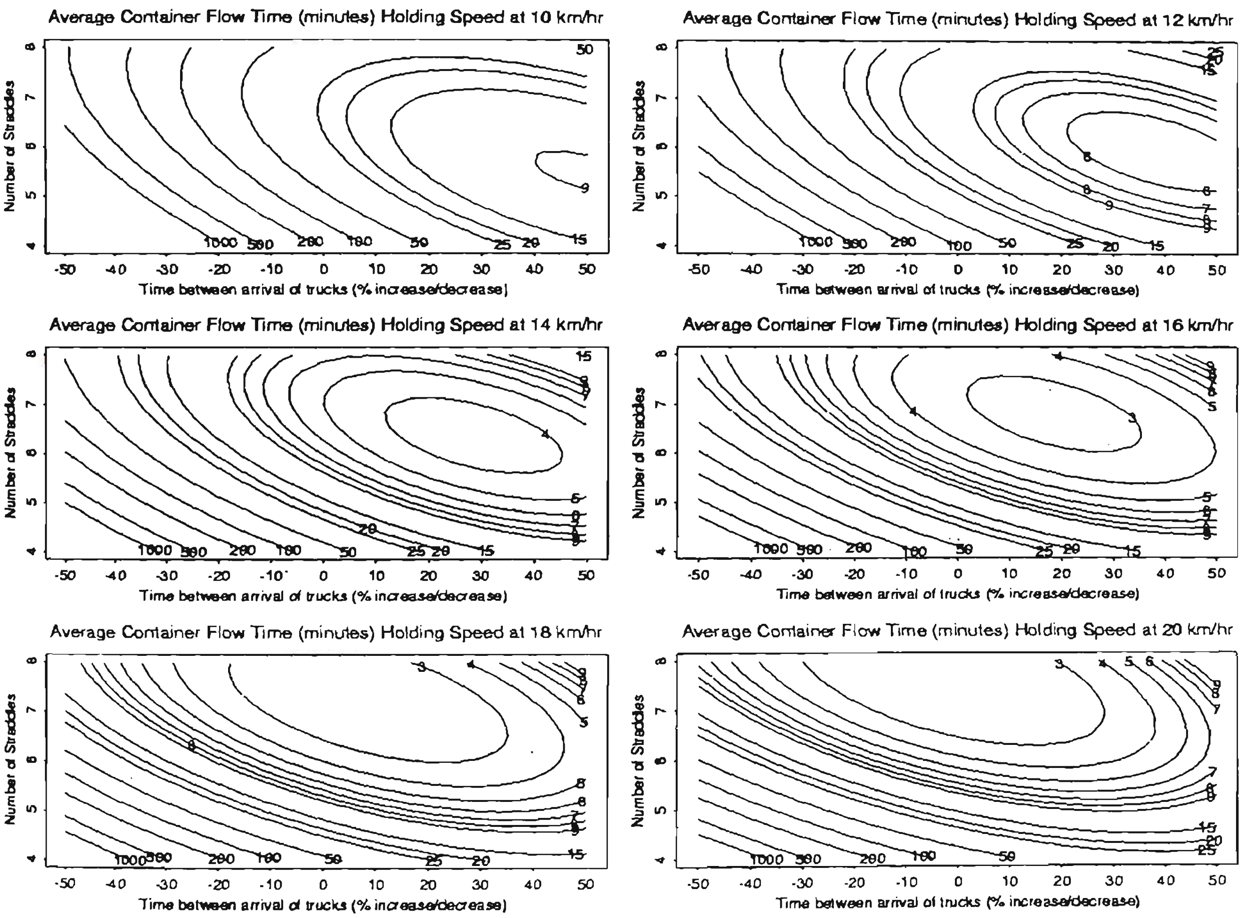


Figure 5.18. Contour plots show average container flow time as a function of the number of straddles and time between arrival of trucks for various values of straddle speed using the present selection strategy.

Figure 5.19 presents a contour plot of the surface generated by Equation 5.13 for the proposed selection heuristic rule. The contour plot shows a similar flow time with the present set-up. In general, it is observed that when the straddle speed increases, the average container flow time decreases.

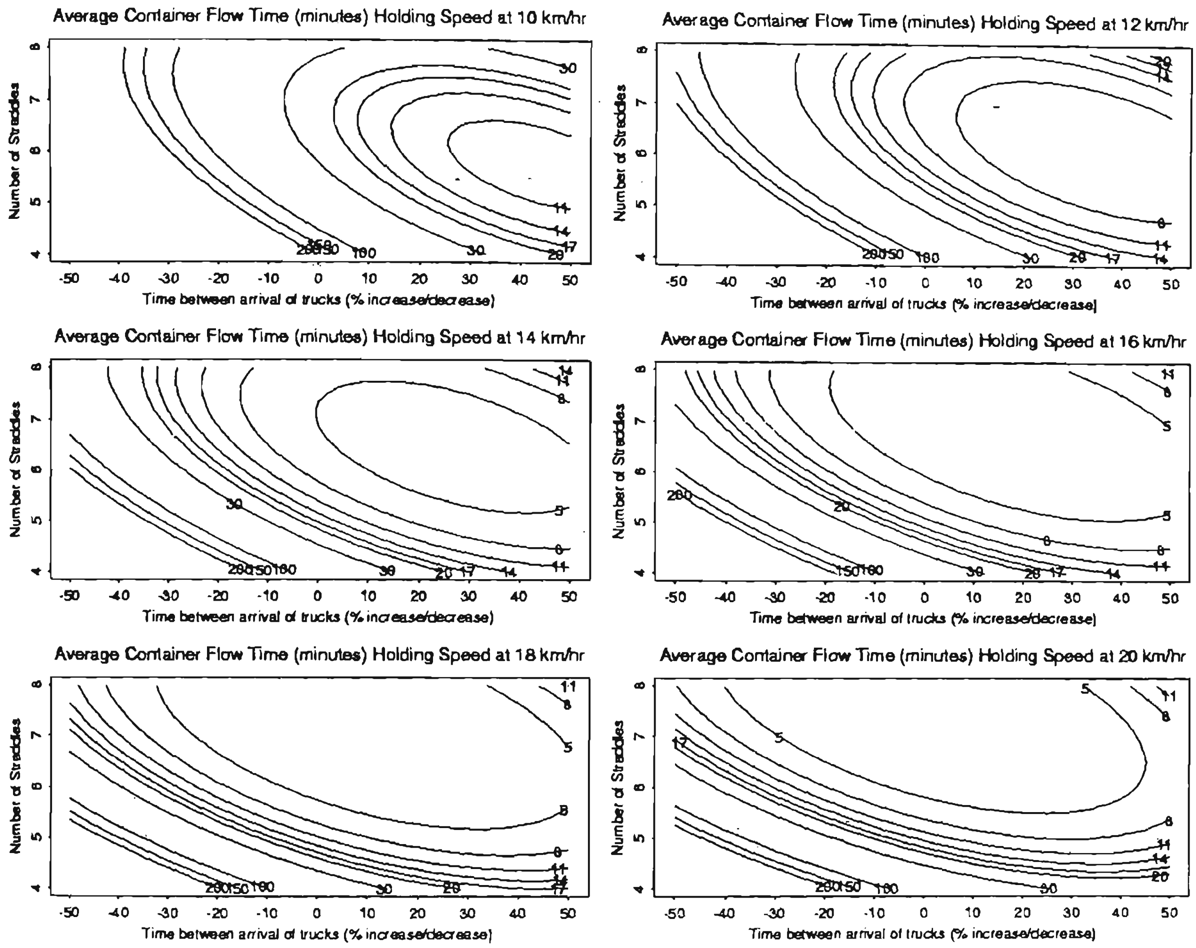


Figure 5.19. The fitted surfaces: Contour plots show average container flow time as a function of number of straddles and time between arrival of trucks for various straddle speeds under proposed heuristic selection rule.

Figure 5.20 presents a contour plot of the surface generated by the Equation 5.9 under the POR rule. In the same figure the average total daily throughput under the present set-up increases with an increase in the speed of the straddles. It indicates that at a speed of 20 km/hr, a total throughput of around 900 containers per day can be obtained. When the number of straddles increases from 6 to 7, the daily throughput also increases with an increase in speeds from 10 to 16 km/hr under the present set-up.

When the straddle speed is above 16 km/hr, the daily throughput is not increased further with the present arrival rate when the number of straddles increases from 6 to 7. This implies that with the present rate of arrival of trucks, 6 straddles are the best for speeds between 14 and 16 km/hr. However, a further increase of 10% in the arrival rate of trucks from the present rate would cause an increase of throughput with an increase of speed.

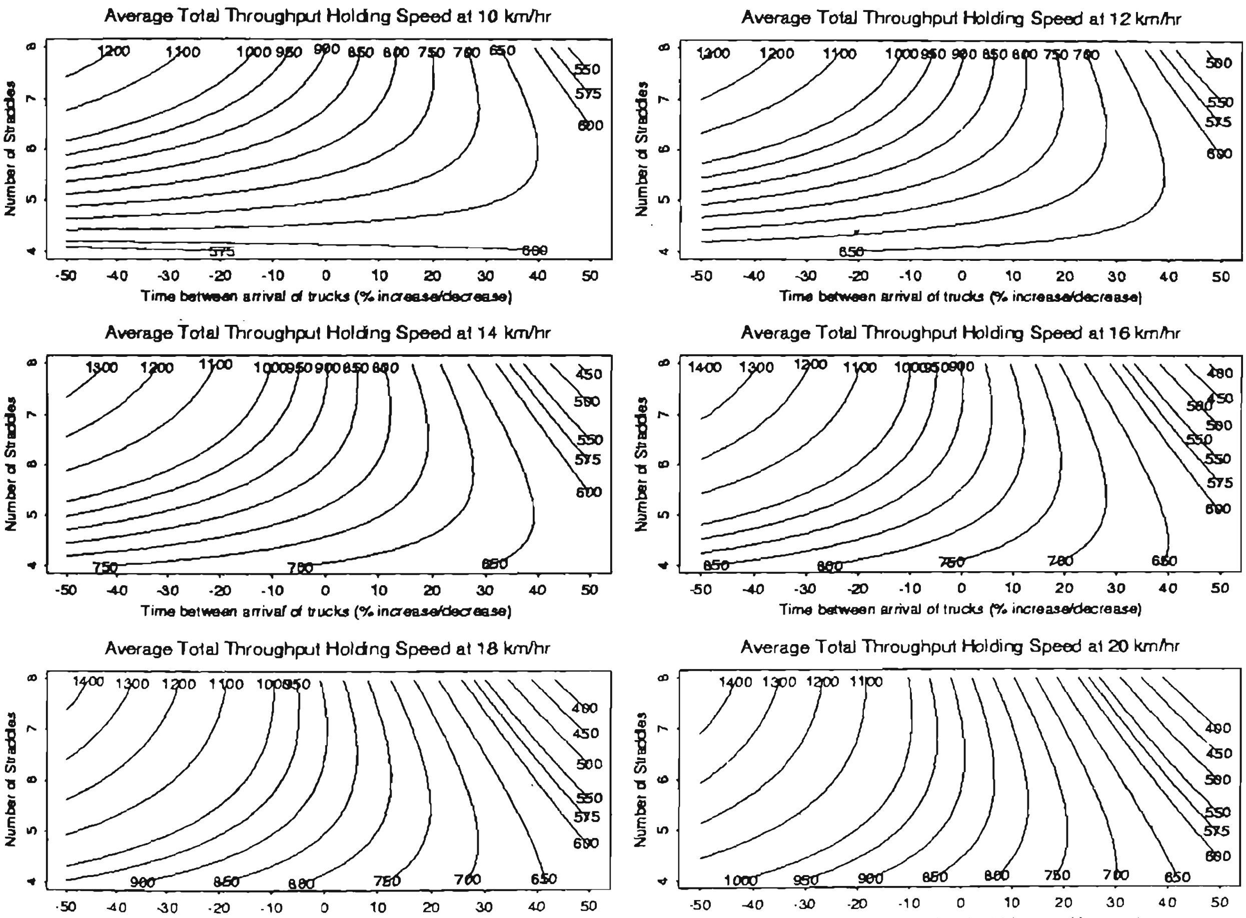


Figure 5.20. The fitted surfaces: Contours show total throughput (TEUs/day) as a function of number of straddles and time between arrival of trucks for various straddle speeds under present selection strategy.

Similar observations are made under the proposed SDS rule as can be seen in Figure 5.21 generated by the Equation 5.14. At a higher speed of 20 km/hr under the SDS rule, the daily throughput increases to around 900 containers with six straddles. Increasing the number of straddles from 6 to 7 under the SDS rule increases daily throughput with an increase in speed at the present arrival rate. This indicates that the SDS rule and POR rule performs equally well on throughput with a higher straddle speed.

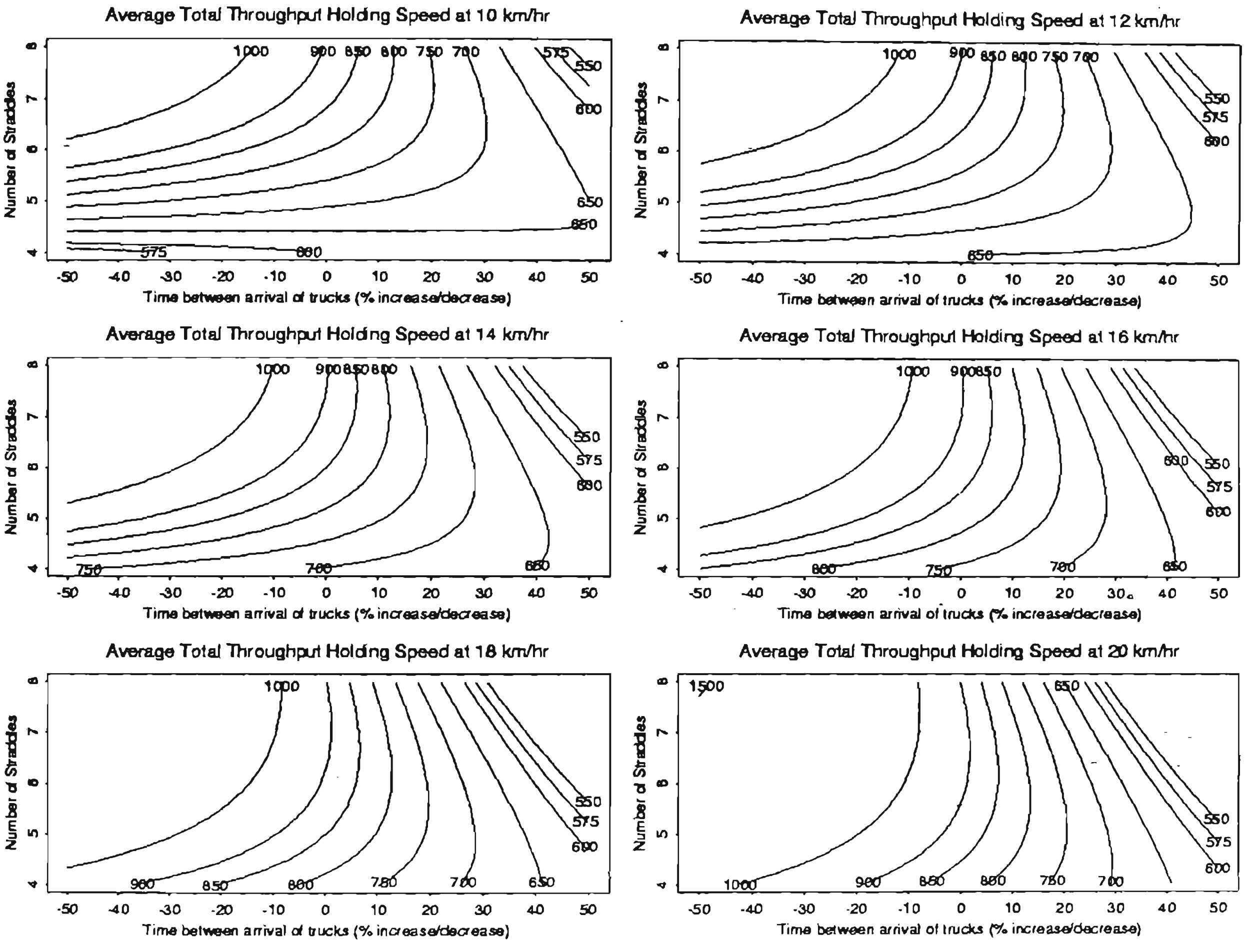


Figure 5.21. The fitted surfaces: Contour plots show total throughput (TEUs/day) as a function of number of straddles and time between arrival of trucks for various straddle speeds under proposed heuristic selection rule.

Figures 5.22 and 5.23 presents contour plots of the surface generated by Equations 5.10 and 5.15. In Figure 5.22, straddle utilisation increases at a very low speed. Increasing straddles from 6 to 7 at the present rate shows low utilisation with an increase of speed. However the present set-up shows high utilisation of straddles. Figure 5.23 indicates similar observations for straddle utilisation under the proposed heuristic selection rule. Both rules performed equally well on straddle utilisation with increased speeds.

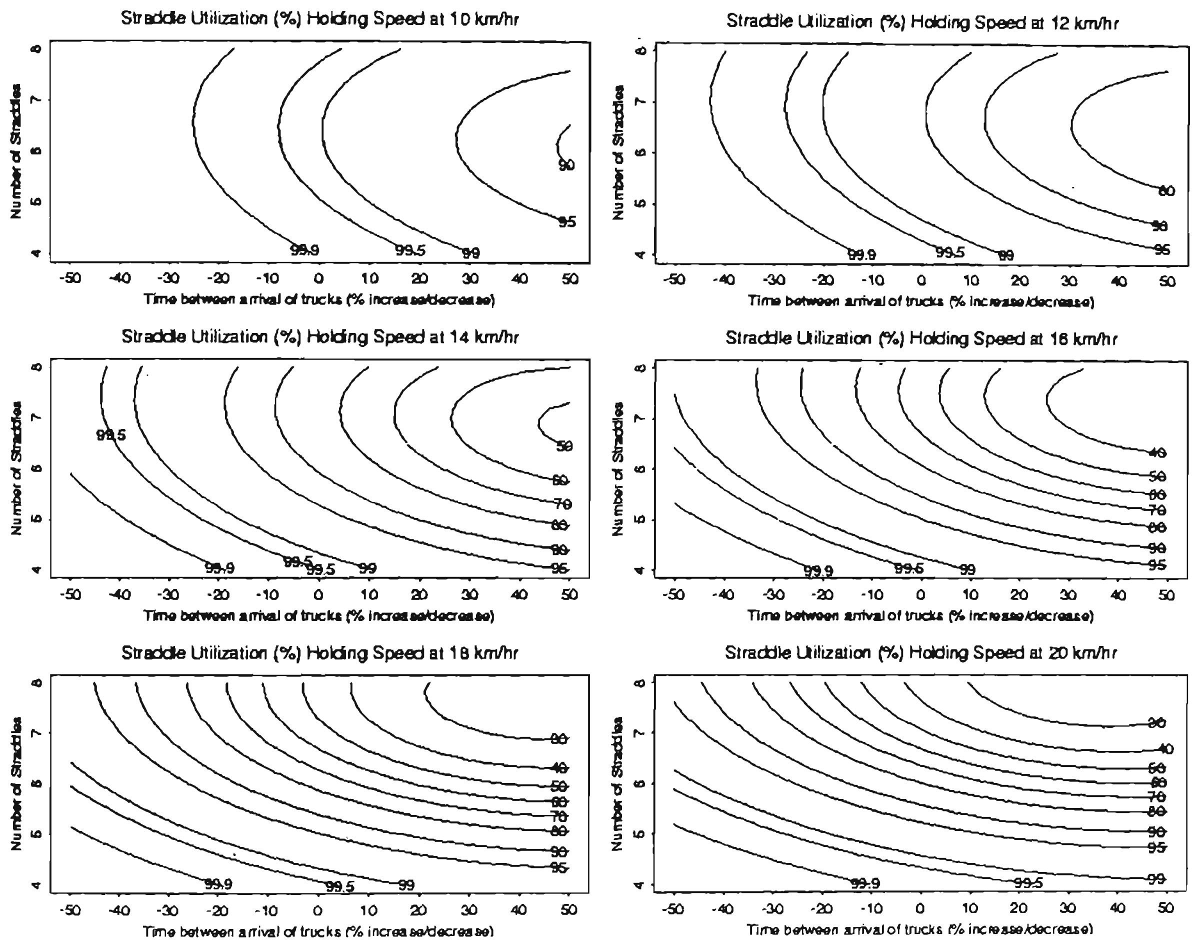


Figure 5.22. Contour plots show average straddle utilisation as a function of the number of straddles and time between arrival of trucks for various values of straddle speed under present selection strategy.

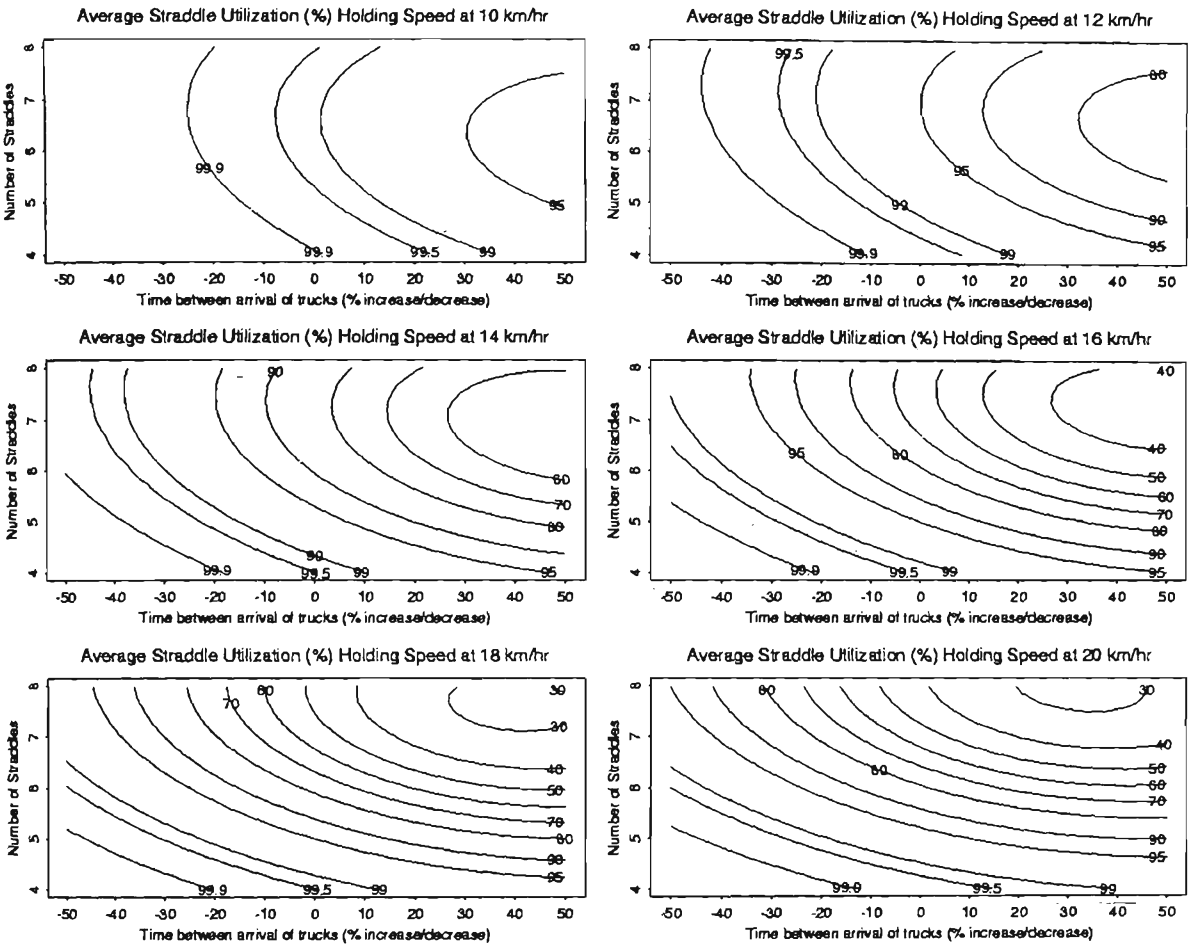


Figure 5.23. The fitted surfaces: Contour plots show average straddle utilisation as a function of number of straddles and time between arrival of trucks for various straddle speeds under proposed heuristic selection rule.

Figures 5.24 and 5.25 present contour plots of the surfaces generated by Equations 5.11 and 5.16. Figure 5.24 shows the average waiting time of jobs in the queue for straddle service decreases with an increase in speed of straddles under the present set-up. An increase of straddles from 6 to 7 with an additional 10% of trucks from the present rate decreases the waiting time significantly at higher speeds of the straddles. With the present set-up the minimum average waiting time of trucks can be achieved with 7 straddles when the speed range is from 16 to 20 km/hr.

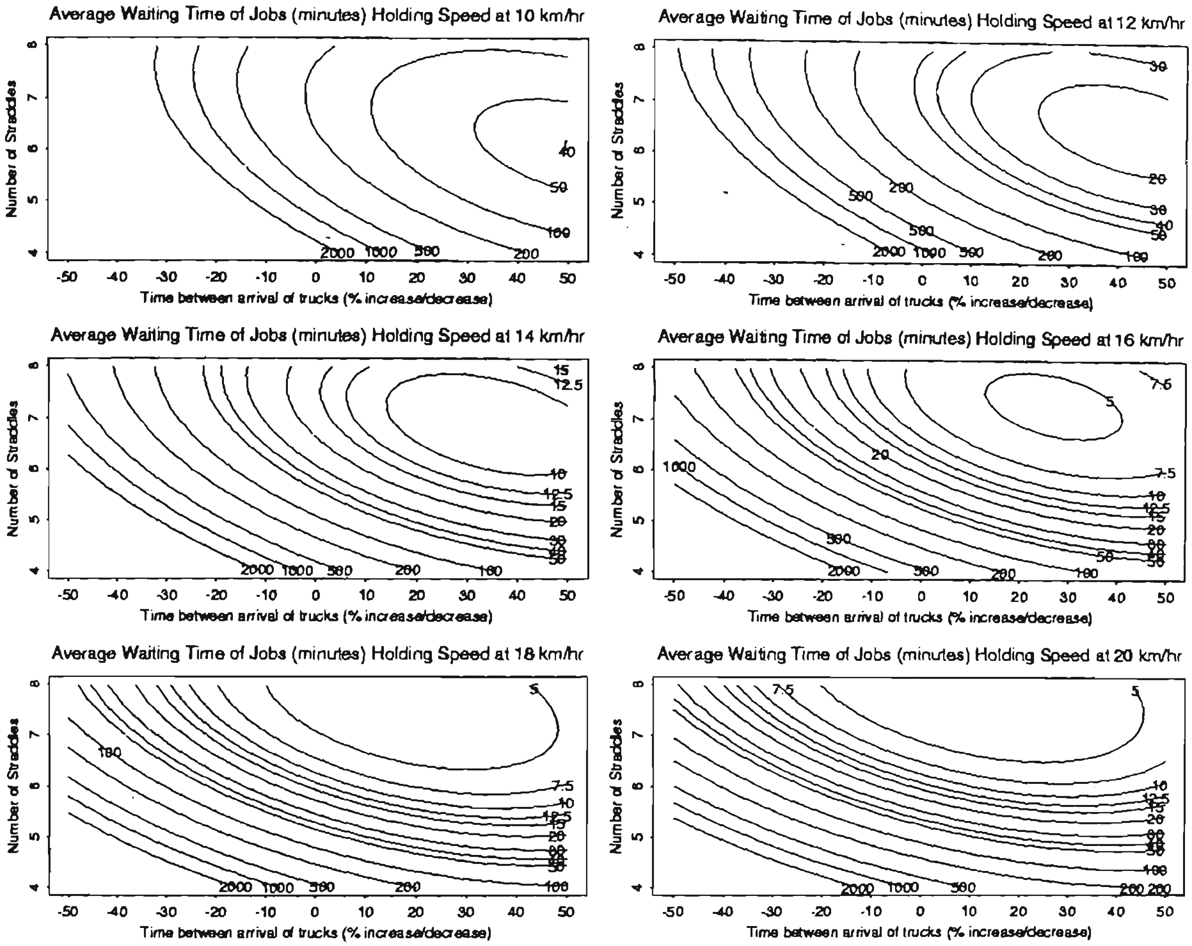


Figure 5.24. The fitted surfaces: Contours show average waiting time of jobs in queue for straddle service as a function of number of straddles and time between arrival of trucks for various straddle speeds under present selection strategy.

Under the SDS allocation rule the average waiting time as shown in Figure 5.25 suggests that there is no significant change in the waiting time at higher straddle speeds as compared to the present allocation strategy. Therefore, both rules performed equally well on the waiting time of jobs at higher speeds.

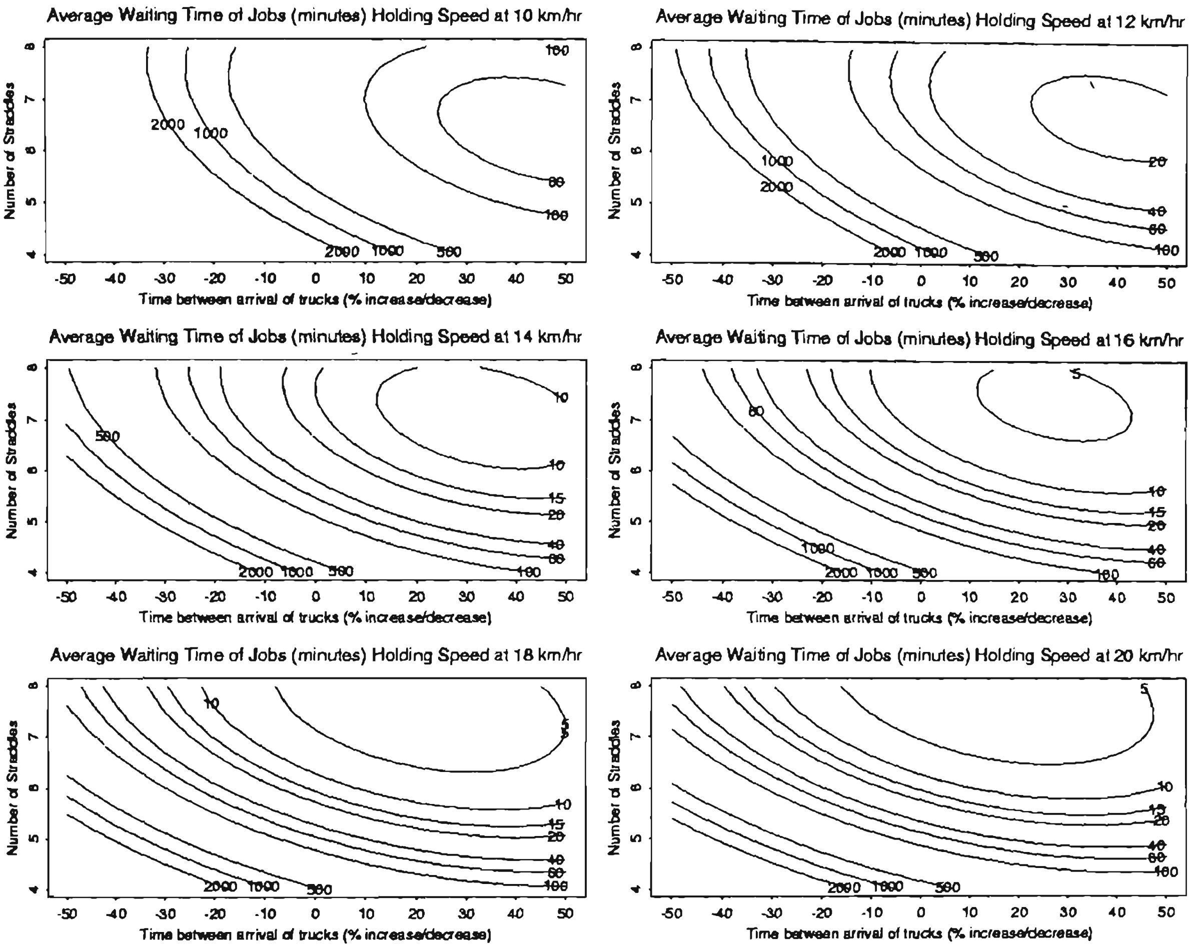


Figure 5.25. The contours show the average waiting time of job requests in the queue for service by straddles as a function of number of straddles and time between arrival of trucks for a number of straddle speeds under proposed heuristic selection rule.

Figures 5.26 and 5.27 present contour plots of the surfaces generated by Equations 5.12 and 5.17. The average number of jobs in the queue for service of straddles decreases with an increase in speed under the present set-up (see Figure 5.26). Any increase in trucks causes an increase of queue length with the present set-up. This is more predominant at lower straddle speeds. Changing the number of straddles from 6 to 7 reduces the queue length dramatically with change in speeds.

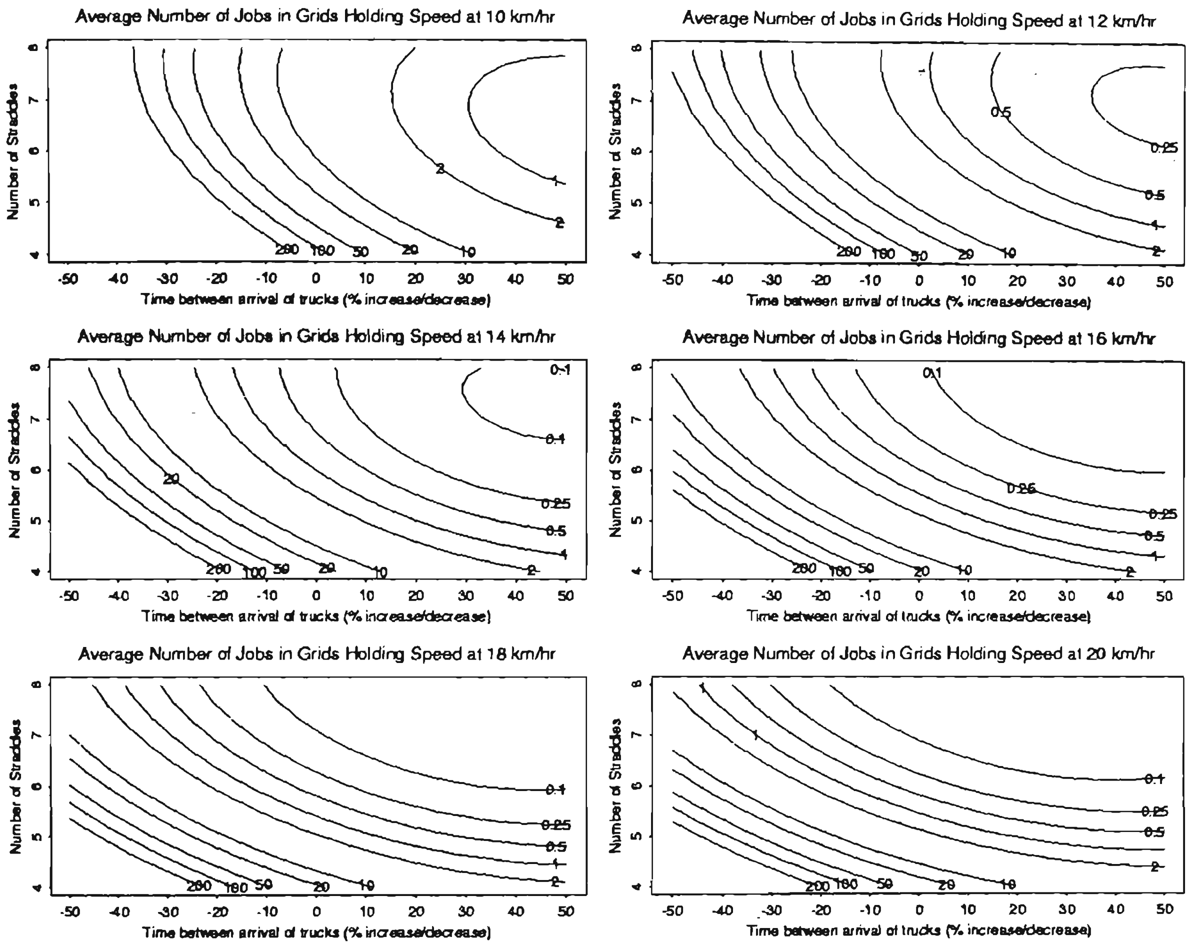


Figure 5.26. The contours show the average number of jobs in the queue for service by straddles as a function of the number of straddles and the time between arrival of trucks for a number of straddle speeds using the present selection rule.

Similarly Figure 5.27 shows there is very little difference between the proposed SDS rule and the present rule for queue length. Both rules perform equally well on number of jobs waiting in queue at higher speeds.

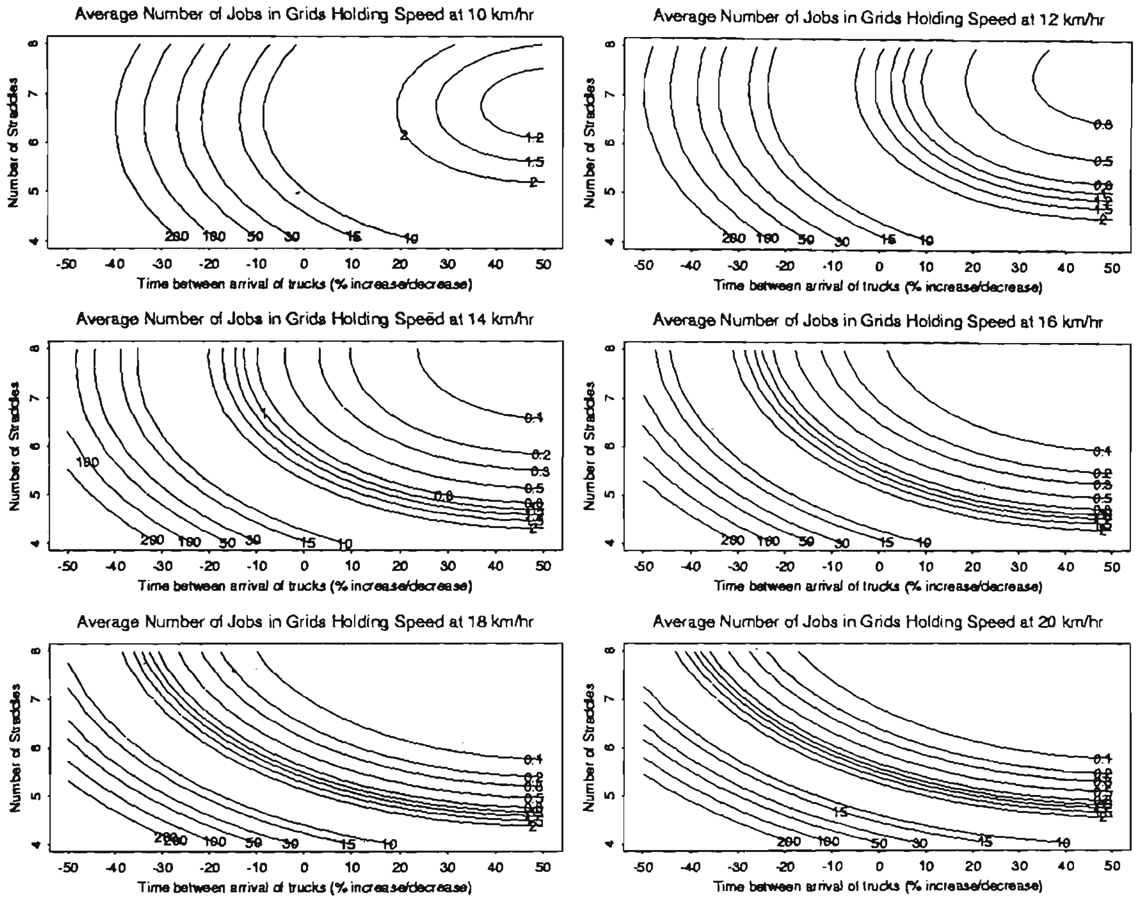


Figure 5.27. The contours show the average number of jobs waiting in the queue for service by straddles as a function of straddles and the time between the arrival of trucks for various straddle speeds under proposed heuristic selection rule.

5.15. Conclusions

The preceding discussions demonstrate the use of simulation as a tool to evaluate the performance of a container handling system in marine container terminals. This chapter highlights various modelling issues faced and how they were solved in the modelling of this container handling process. Simulation experiments revealed that the system is very close to optimal under the present set-up.

An increase in the number of straddles from 6 to 7 under the present set-up improves daily throughput by an average of 13 containers only. However, a further increase of straddles results in no further increase in daily throughput. A 10% increase in trucks can be met by the existing 6 straddles but the container flow time increases from 5.55 minutes to 6.88 minutes. This increases the average waiting time of jobs on grids to 38.16 minutes from the present waiting time of 22.96 minutes. If the primary goal is to reduce the container waiting time on grids, it may be a possibility to increase the number of straddles to 7 under the present set-up. This can reduce the average waiting time of trucks on grids from 16.58 minutes to 8.86 minutes, a decrease of 46.5%. Moreover, a decrease of 46.5% truck waiting time can meet the requirements of shorter turnaround time of trucks in a terminal.

The job assignment rules for straddles were tested in this study. The results revealed that both POR (present strategy) and SDS (proposed strategy) performed equally well in average container flow time, daily throughput, average waiting time of jobs, number of jobs in the queue for service by straddles, and straddle utilisation when the straddle speed is 15 km/hr. Examination of the fitted surfaces shows that there is no difference between the proposed rule and present rule in terms of the performance measures. For example, if the straddle speed is 20 km/hr then both the POR and SDS rules result in a throughput of 900 containers per day. The simulation result suggests that a SDS rule cannot be considered as the best strategy to implement in the terminal.

The performance measures under the present set-up are significantly affected by the straddle speeds because among all operation parameters, the straddle speed seems to be the most important factor. However, maintaining the higher speed could achieve better performance in the present set-up. Maintaining a higher speed depends on the straddle carrier drivers. Maintaining higher speeds at all times by the drivers is not possible due to restricted routes in the terminal. Simulation results indicate a very high utilisation (around 85%) of straddles in the present set-up. A very high utilisation in the system usually indicates an imbalance in the throughput capacity. To improve the lower straddle utilisation, one more straddle can be deployed in the present set-up.

The system performance is also affected by the visitation sequences of straddles in the yard blocks of North Park. Further studies can be performed to evaluate the impact of change of the visitation sequence of containers in yard blocks under the present set-up and related parameters. The visitation sequences of straddles are greatly influenced by the allocation of export and import containers. The next chapter will discuss the present practices of management information systems at marine container terminals.

CHAPTER 6

MANAGEMENT INFORMATION SYSTEMS USED IN MARINE CONTAINER TERMINALS IN AUSTRALIA AND ASIA

6.1. Introduction

As a result of the research presented in this thesis it has been established that there is a plethora of performance indicators used by operators of container terminals. This makes it difficult to compare the performance of different terminals. Nonetheless it is possible for individual terminals to improve their own performances. In chapters 4 and 5 we have shown how computer simulation is a useful management tool for exploring a range of operating strategies. A key factor in measuring performance indicators and optimising an existing operation is ready access to information. In a container terminal one of the most fundamental pieces of information is the locations of the containers themselves. Other pieces of information relate to the arrival of trucks to the terminal, interactions with customs, banks, shipping companies and so on. In this chapter the results of a questionnaire relating to the use of information systems in Australian and Asian container terminals are reported. As a result of the study it is conducted that over the last decade information technology has brought about significant advantages in terms of speed, efficiency and cost reductions. However, half of the container terminals in Australia that handle less than 10 000 TEUs per month do not use modern computing technology in their operations.

Management information systems are one of the main factors influencing terminal operations together with operating strategies, physical layout of terminals, work practices, and yard layout (Kozan, 1997). In recent years, management information systems have played a major role in improving the productivity of container handling operations at marine container terminals throughout the world. The main goal of management information systems is to facilitate the movement of containers through the terminal so that containers spend a minimum of time within the terminal system. Within the management information system, four areas have evolved most rapidly: electronic data interchange

(EDI), automatic equipment identification (AEI), global positioning systems (GPS), and position determination systems (PDS). The full implementation of information systems not only increases the capacity of terminals but it reduces the need for investment in infrastructure, particularly storage facilities in yard areas. One of the important factors, EDI and information technology may have a significant impact on the capacity and adequacy of Australian ports in the foreseeable future (BTCE, 1995).

Walker and Helmic (1998) note that an increase in the utilisation of existing terminal assets and related infrastructure can often be found in the areas that relate to the application of information technology. Expanded use of AEI, EDI, handling computers, and automated container-handling equipment may result in meaningful improvements in terminal productivity.

Implementation of EDI in Australia has been significant in the area of regulatory messaging. However, the uptake of EDI in commercial and operational activities has been comparatively slow (PC, 1998a). Despite being recognised as a major contributor to overall efficiency, modern management information systems have been unevenly implemented at marine container terminals.

GE information services commissioned a survey of European shippers and carriers to establish a comparison between shippers and carriers of their attitudes to and priorities for different types of information services in 1992 (Absalom, 1992). The results of this study related to the role of information systems.

Holguín-Veras and Walton (1996b) conducted a similar study in the context of US container terminals. In their study, a survey was conducted with the co-operation of the Information Technology Committee of the American Association of Port Authorities. They concluded that significant savings could be achieved in the activity of container location equipment. The data provided by the survey indicated that, for a typical terminal, the information flows among agents and within terminals are very loosely integrated.

There is great pressure to reduce labour costs and impose efficiency to be competitive (Stirling, 1989). Internal pressures common to all container terminal operation businesses include the need to stay competitive, reduce operating costs, improve profitability and provide better management information. In addition there are external pressures such as the need to improve the quality of services provided to transport companies and shipping companies, and there are also increasing requirements for all forms of electronic communication with entities such as customs, brokers, trading banks, and regulating authorities. The support of effective management information systems is essential to be able to satisfy these demands. In view of the significant increase in containerised cargo and its unitised nature there is considerable scope for automation in container terminals as well. Figure 6.1 shows the principal applications areas, which illustrate the relationship between information system applications and external entities.

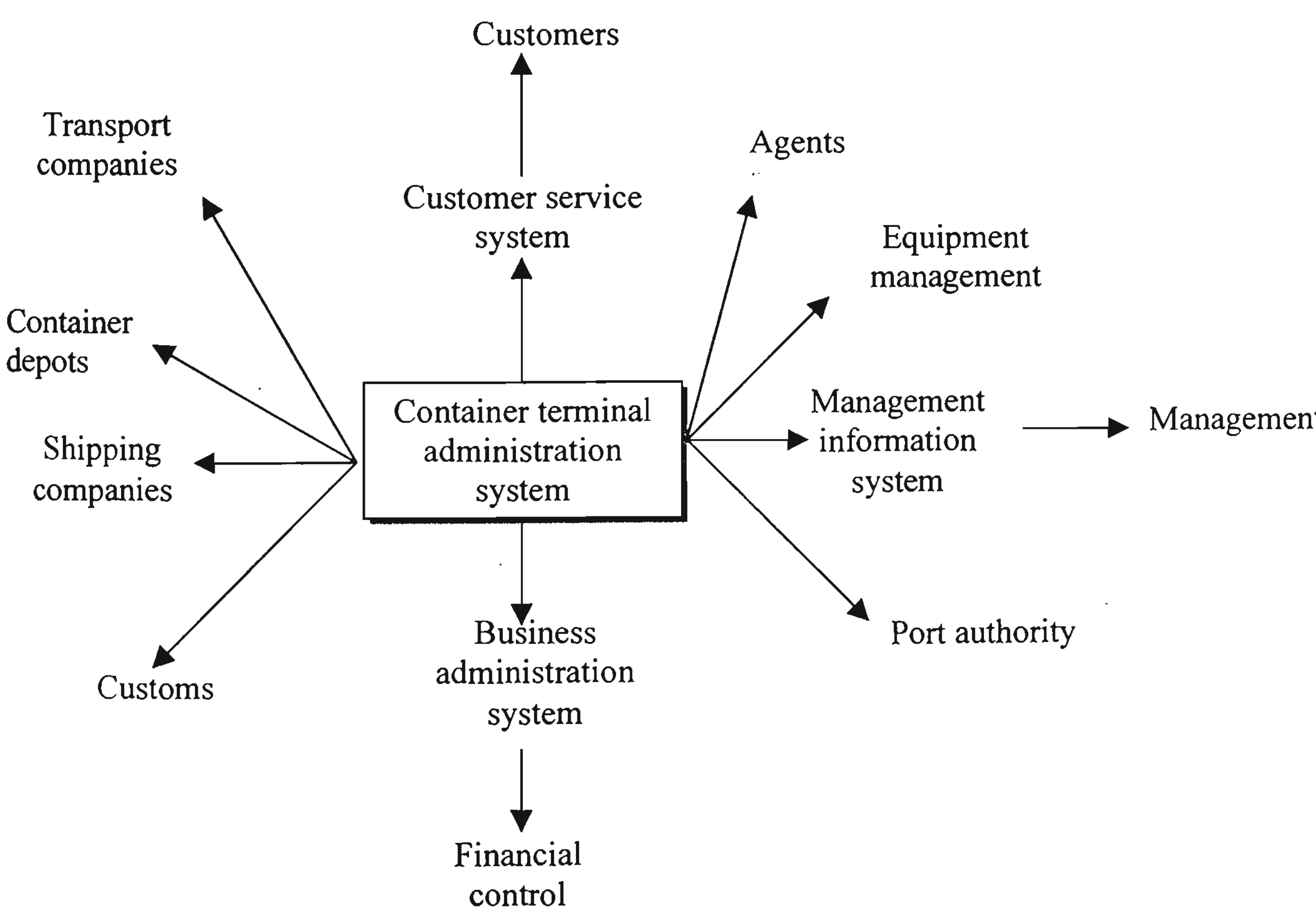


Figure 6.1. Principal application areas of management information system.

The main objective of this chapter is to provide a comparison of the present utilisation of management information systems in Australian and Asian container terminals. The survey not only focused on the information of management systems but it also provides information on the practice of automation.

6.2. Analysis of responses to survey

Responses to a survey of current practice of information management system provided a clear picture of current practices of Australian container terminals in comparison to the best overseas container terminals in Asia. A written questionnaire was circulated among the selected container terminals in both Australia and Asia (see Appendix I). The questionnaire was sent to 17 and 48 organisations within Australian and Asian container handling industries respectively. In Australia, one questionnaire was returned uncompleted due to an incorrect address and two questionnaires were sent back because there were no container handling operations. Two questionnaires were returned from overseas due to incorrect addresses. However the total responses received were six and eighteen from the Australian and Asian terminal operators respectively.

Therefore, the percentage of responses in Australia was 35.29, and the percentage of response from overseas (Asia) was 37.5. The list of the states in Australia and the countries selected in this study are given in Tables 2.14 and 2.15 of chapter 2.

The survey, a questionnaire, consisted of eight sections. The first section, general information, gathered information about the use of modern information systems and information technologies and various activities involved in the export and import processes. The second section, information about container location systems, gathered information about the performance of the internal activities. The third section, information about the gate system, gathered information about gate activities. The fourth section gathered information on the use of electronic data interchange. The fifth section, information about container-status inquiry system, focused on the type of system, end users to the system and level of use. The sixth section, information about the other interactions, focused on the method of releasing freight, bills of lading and verification of credit of transport carriers. The seventh section, about the future, gathered the respondents' perceptions about the future of information technology. The eighth section, container handling equipment and automation, focused on quay crane operations and automation.

The terminals in Australia and Asia were assigned identification codes (from AU1 to AU6 and A1 to A18) for the reasons of confidentiality that we guaranteed. The terminals that were surveyed display a wide variety of characteristics. The numbers of containers handled per month are presented in Figure 6.2 in Australian and Asian container terminals. Analysis of the survey was carried out on the basis of terminals' responses to each question. Those terminals that did not respond to the questions are not included in the analysis.

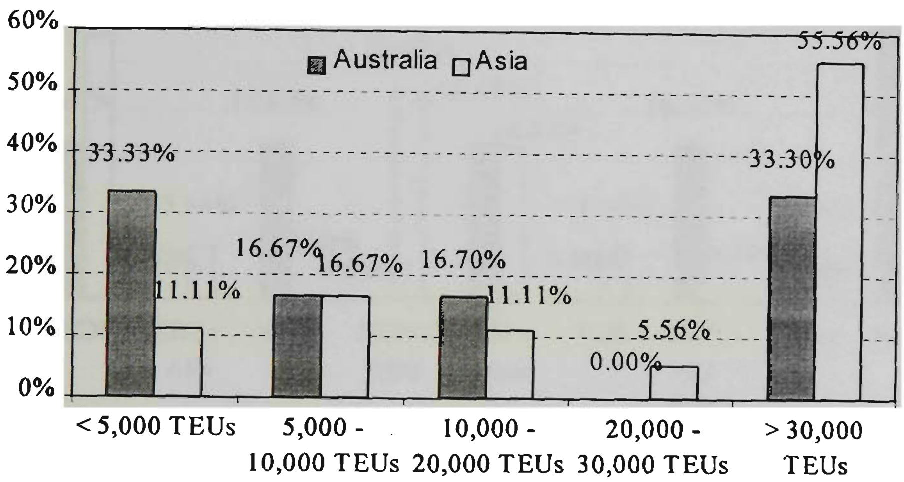


Figure 6.2. A comparison between Australian and Asian container terminals according to size of container handling operations.

6.3. Operating systems

The representatives of the container terminals both in Australia and Asia were asked to state whether terminals implemented a computer integrated terminal operations system (CITOS) to support container operations. Analysis of survey indicates that 50% of container terminals in Australia are using CITOS against 83.30% of Asian terminals. CITOS utilises expert systems, equipment and automation and real time process control software to improve productivity. The advantage of having this system is that it provides a linkage between all the computer systems to generate an overall perspective on terminal planning and operations. Operating in real time, CITOS will result in better matching of supply and demand of resources.

We can see from Figure 6.3 what management information systems (MIS) and information technology are implemented by Australian and Asian container terminals. As the figure shows, 33.33% of container terminals in Australia do not use any management information system (MIS) and information technology (IT) against 16.67% of terminals in Asia. However, most common among all terminals is electronic data interchange (EDI). In Australia, 16.67% of terminals are using all technologies such as EDI, automatic equipment identification (AEI), position determination system (PDS), and global positioning system (GPS). For terminals both in Australia and Asia, 16.67% are using EDI along with other IT.

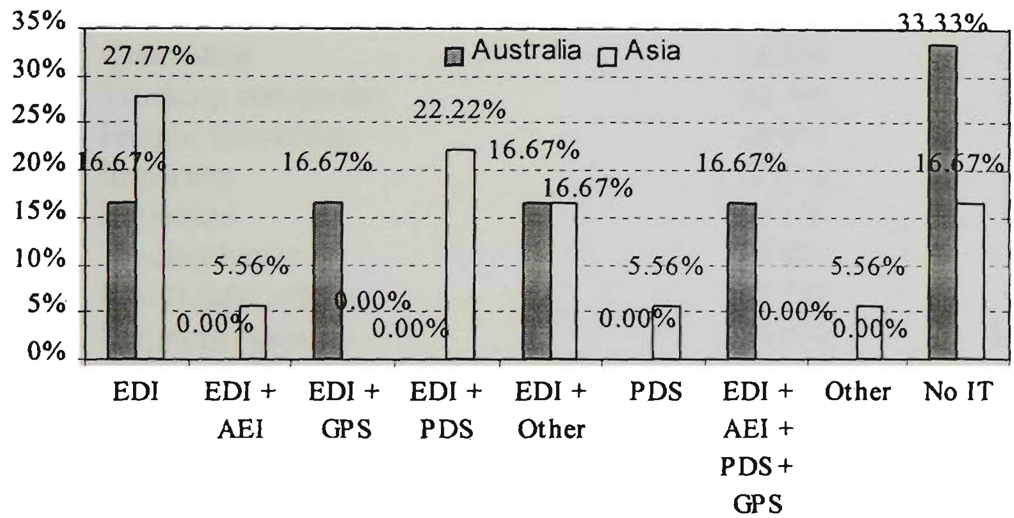


Figure 6.3. A comparison of modern information system and information technology applied in Australia and Asia.

Under the "EDI and other" category, only one terminal in Australia reported the use of radio data terminals (RDT) in all equipment, whereas among Asian terminals radio data transmission equipment control and mobile data units (MDU) connected to yard operations computer systems are widely used. However, under "other" category, one terminal in Asia reported the use of an in-house system. The same figure shows that automatic equipment identification (AEI) is not in widespread use.

6.4. Import and export container processes

The daily activities of container terminal operations involve a fairly large number of different agents related to importing and exporting containers (see Table 6.1). The same table shows none of the terminals in Asia is interacting with trading banks as against 29.4% of terminals in Australia.

Table 6.1. Interactions of daily activities of container operations with various agents.

Serial number	Interacting agents of a container terminal	Percentage use in Australia	Percentage use in Asia
1	Other container terminal operator	64.7%	33.3%
2	Shipping companies	100.0%	100.0%
3	Customs brokers	64.7%	16.7%
4	Port authorities	58.8%	66.7%
5	Cargo insurers	11.8%	16.7%
6	Quarantine	58.8%	67.7%
7	Trucking companies	82.4%	67.7%
8	Freight forwarders	58.8%	33.3%
9	Importers	47.1%	33.3%
10	Exporters	47.1%	33.3%
11	Trading banks	29.4%	0.0%
12	Rail freight offices	47.1%	50.0%
13	Shipping agencies	76.5%	100.0%
14	Container depots	76.5%	33.3%

Table 6.2. Information flow on processes of import containers among various agents.

Serial number	Information on import processes	% use in Australia	% use in Asia
1	Notifies consignees of arrival notice between shipping companies and brokers	50.0%	17.6%
2	Freight release information between shipping companies and terminal operator	66.7%	35.3%
3	Container availability information between transport companies and terminal operator	83.3%	58.8%
4	Information about container status between brokers and trucking companies	33.3%	29.4%
5	Clearance information between brokers and port authorities	66.7%	52.9%
6	Forward bill of lading or delivery order between brokers and transport companies	0.0%	29.4%
7	Container released information between regulating agencies and management	66.7%	52.9%
8	All above mentioned information (from 1 to 7)	0.0%	23.5%
9	Other	0.0%	17.6%

The agent that is interacted with the least in container terminal operations in Australia and Asia is the cargo insurer. These activities can be depicted as an activity network that captures the fundamental structure of the process.

A detailed examination of all the interactions between various agents is beyond the scope of this research; the focus was on the most relevant activities of the container terminal operator. However, the interactions between the agents are depicted in Tables 6.1 and 6.2 for import and export processes of containers in terminals.

Fourteen different agents interact with marine container terminals as shown in Table 6.1. The activities both external (activities linking with other agents) and internal (activities within each agent) of the container terminal operator have different requirements of management information systems. The flow of information for import processes is shown in Table 6.2, which shows the comparison between Australia and Asia. In Australia, terminals do not forward bills of lading or delivery orders between brokers and port authorities. In this comparison of the flow of information a distinction is observed among Asian container terminals: 17.6% terminals have requirements of additional information. Among all terminals in Asia, three terminals reported that manifest, arrival condition of vessel, container list, and delivery order are necessary for import container processes.

Similarly, Table 6.3 shows the information required for export processes of containers between Australia and Asia. As is shown, two terminals (33.3%) in Australia stated that additional information was required such as export receival advice (ERA), vessel booking list, and hazardous documentation for export container processing. However, in Asia, 31.2% terminals reported export booking information from shipping companies to terminal operator, export arrival notification, customs approval, and container load list. It is evident that the intensity of this information flow justifies advanced management information system.

Table 6.3. Information flow on export processes of containers among various agents.

Serial Number	Information on export processes of containers	Percentage use in Australia	Percentage use in Asia
1	Forwards dock receipt between terminal operator and shipping companies	50.0%	75.0%
2	Issues ocean bill of lading or similar documents of the title between shipping companies and shippers	16.7%	25.0%
3	Sends bill of lading between shippers and forwarder	0.0%	12.5%
4	Sends original dock receipt between transport companies and terminal operator	50.0%	37.5%
5	Requests for special equipment, if needed between transport carrier and forwarder	33.3%	43.8%
6	Export permits between shippers and port authorities	66.7%	62.5%
7	Secures interchange agreement between shipping companies and transport companies	0.0%	37.5%
8	Other	33.3%	31.2%

6.5. Container location systems

33.3% respondents in Australia have classified the level of difficulty in locating containers in the storage yard area against 11.1% terminals in Asia. However, 66.7% container terminals in Australia are using the training of employees, regular (weekly) inventory checks, use of terminal synchronous planning and real-time control systems (SPARCS), and global positioning systems (GPS) to reduce or eliminate the difficulty of locating containers in the yard blocks. Similarly, 88.9% of container terminals in Asia reported the following information systems and information technology:

A1 Use of computer to determine location;

A2 Use of accurate yard planning and equipment control;

A3 SPARCS tracking system;

A5 Not much movement and stacking system;

A6 Real time updates with the aid of position determination (PDS) and data radio system;

A7 System tracks position of containers on arrival;

A8 Control by computer;

A9 Location changes are updated in real time;

A10 Quality of information system and procedures;

A11 Terminal set up with international standard even though their container yards are not to width;

A12 Information is in real time database;

A13 Yard plan computerised;

A14 Yard control system software used;

A16 Navis SPARCS computer;

A17 Yard already had designed area as per container status; and

A18 Computerised storage control.

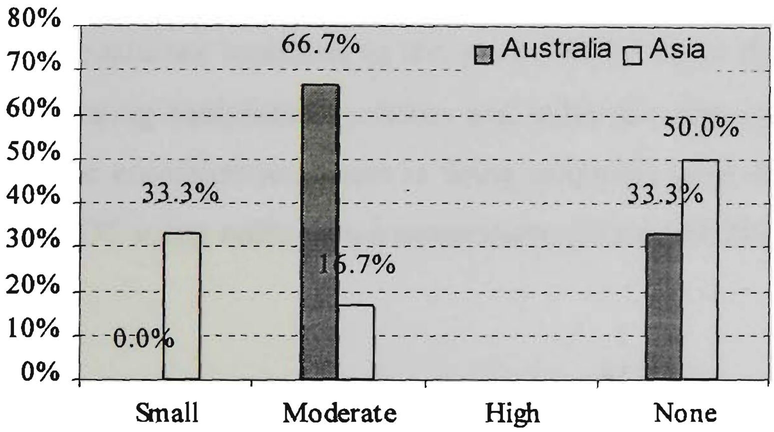


Figure 6.4. Level of difficulty of locating containers in Australia and Asia.

Figure 6.4 shows the level of difficulty of locating containers in the yard classified from small (00.0% in Australia, 33.3% in Asia) to none (33.3% in Australia and 50.0% terminals in Asia). The majority of terminals, 66.7% in Australia 77.8% in Asia, are updating their systems for locating in real time their containers (Figure 6.5). 16.7% in Australia and Asia update location in every shift operation. 16.7% in Australia and 5.6% in Asia are updating daily. However, in one case one terminal (5.6%) in Asia, updates before each vessel's arrival.

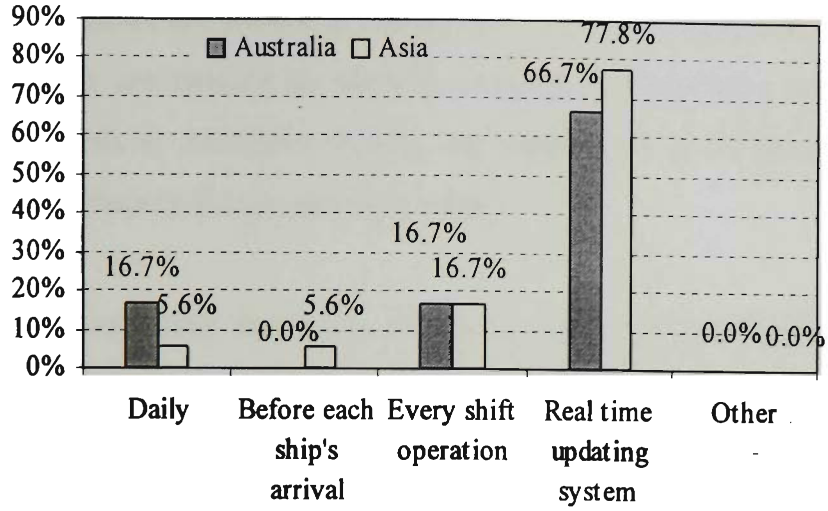


Figure 6.5. Container updating system in Australia and Asia.

33.3% terminals in Australia reported the use of clerks to identify containers (see Figure 6.6) whereas only 17.6% in Asia did. In one case (16.7%) in Australia, GPS is used to perform the task of container locations in the yard. In the same figure, it is shown that 17.6% terminals are using equipment operators and radio data terminals (RDT) in straddle carriers. None of the container terminals is using magnetic strip cards in Australia and Asia. As is shown PDS using radio data transmission system (41.2%) is quite widely used in Asian terminals.

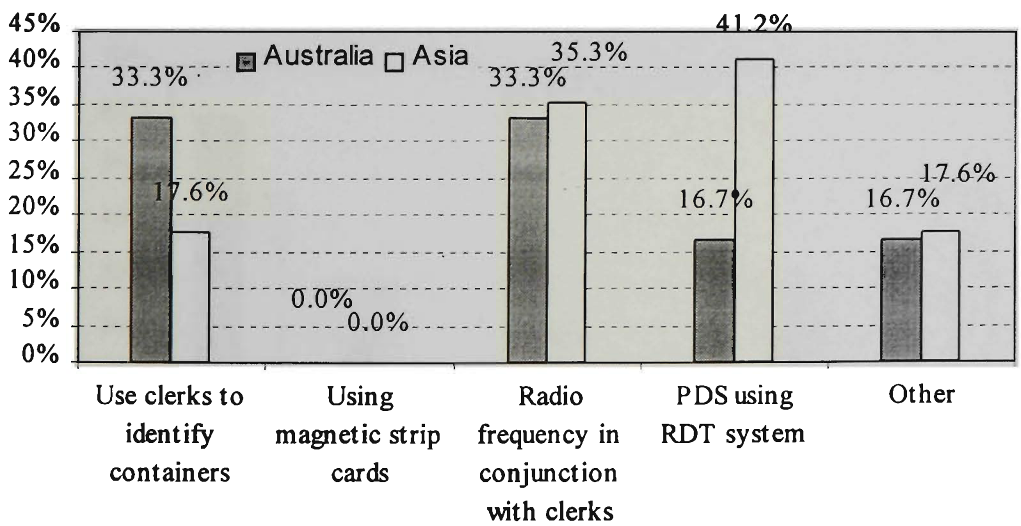


Figure 6.6. A comparison of methods used to perform the task of container locations in the yard between Australia and Asia.

Operators of container terminals were asked to illustrate the number of person-hours needed to update container locations if they are utilising the traditional approach of using clerks. Their responses are shown in Figure 6.7. 37.5% of terminals do not calculate how many person-hours are needed to identify containers when they are using clerks. The majority of terminals in Australia, 60.0%, are spending 0 to 20 person-hrs per month per every 1000 TEUs (twenty-foot equivalent units).

As Figure 6.8 shows, many terminals, 50.0% in Australia and 55.60% in Asia, are using radio frequency devices to transmit container location data to storage, and an additional 5.6% in Asia are planning to implement such systems. Manual and radio frequency are the second most used system type (33.3% in Australia and Asia). In one case in Australia, the information about container location is sent manually. In the majority of terminals, 83.30% in Australia and 88.90% in Asia, the information on container location is stored in computers (see Figure 6.9). The most common uses of this information (see Figure 6.10) are to produce the yard plan (100.0% in Australia and 94.4% in Asia), for statistical purposes (16.7% in Australia and 55.6% in Asia), and book keeping (33.3% each) followed by "other" (16.7% each) purposes. Under the "other" category one terminal in Australia is used for vessel planning, and three terminals in Asia are used for vessel loading planning and delivery, and billing system.

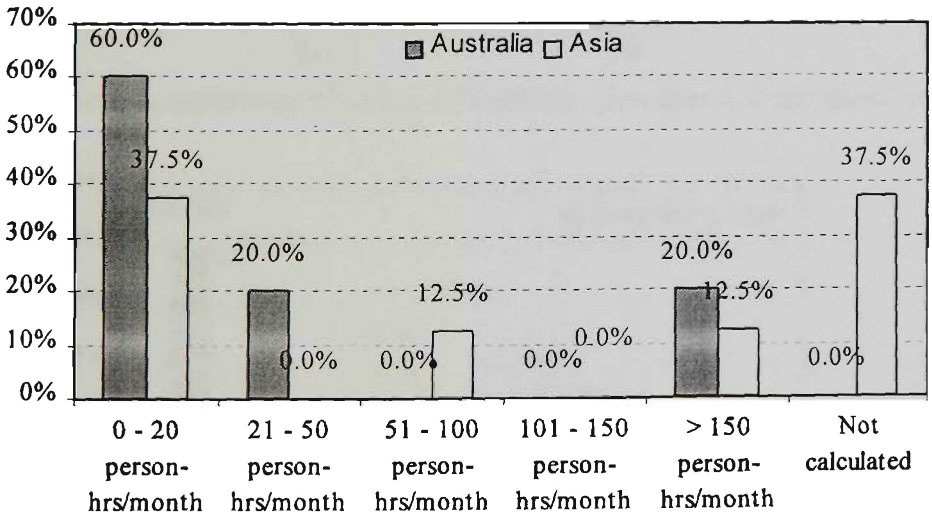


Figure 6.7. Comparisons of person-hours per month spent in updating container location in Australia and Asia.

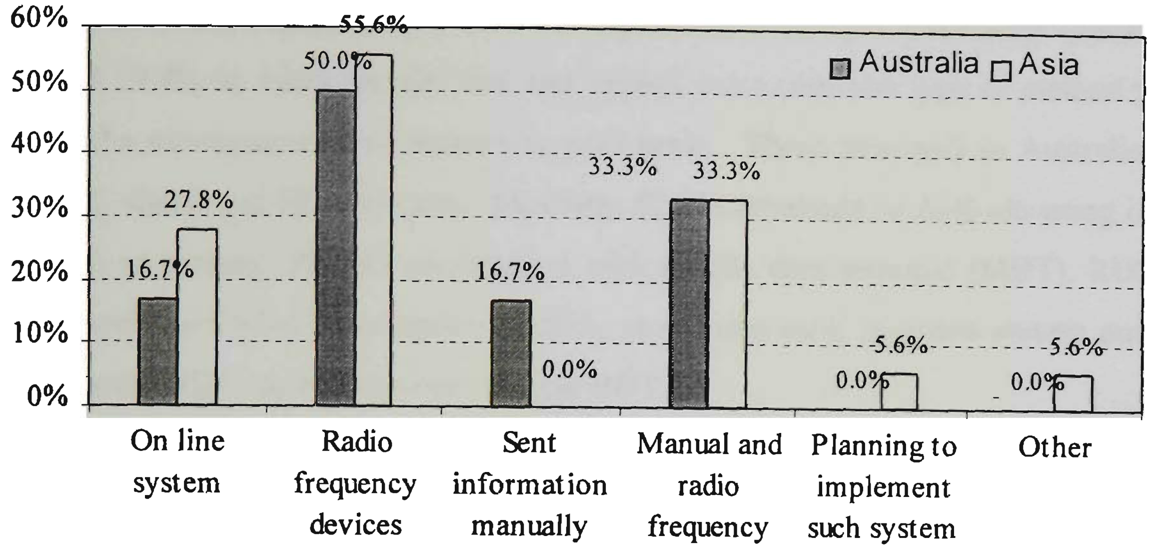


Figure 6.8. Characteristics of container location processes: technology used to send data to storage in Australia and Asia.

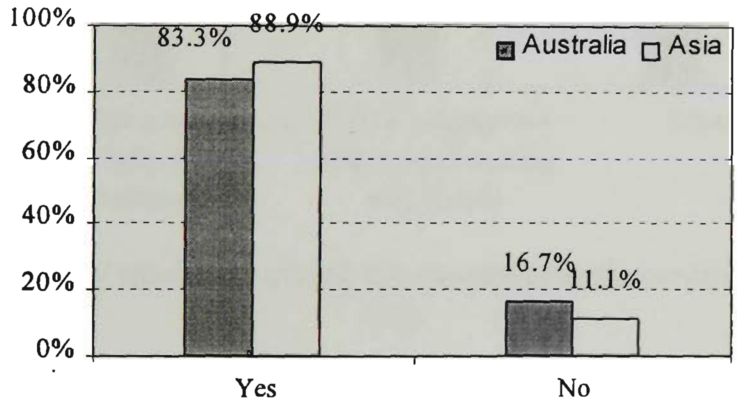


Figure 6.9. Statistical comparison of using of container location information in computers.

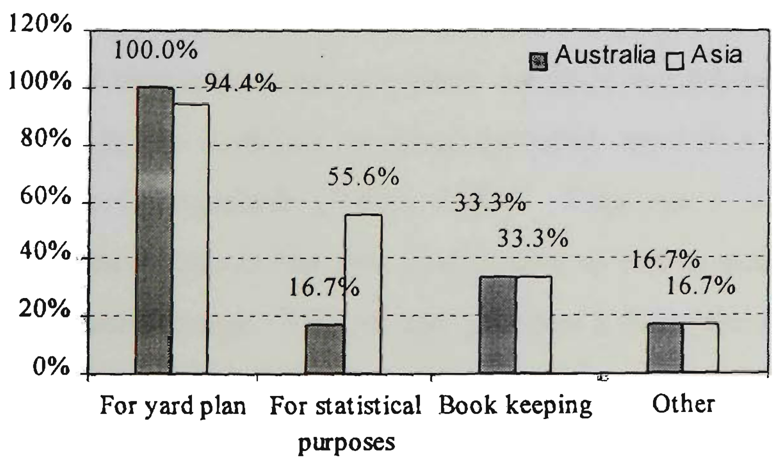


Figure 6.10. Comparison of application of container location information.

Figure 6.11 shows the PDS in conjunction with cargo handling real system (40.0% in Australia and 35.3% in Asia); and the PDS in conjunction with RDT technology (20.0% in Australia and 29.4% in Asia) are the first and second most common type of method used for tracking the movements of containers in yard areas. Three terminals in Australia are using manual, visual and RDT system. Similarly 52.9% terminals in Asia are using other methods such as manual, PDS in conjunction with mobile data terminal (MDT), RDT in conjunction with yard plan of computer system, movement card, in-house system and on line update using MDT, equipment control, and RDT.

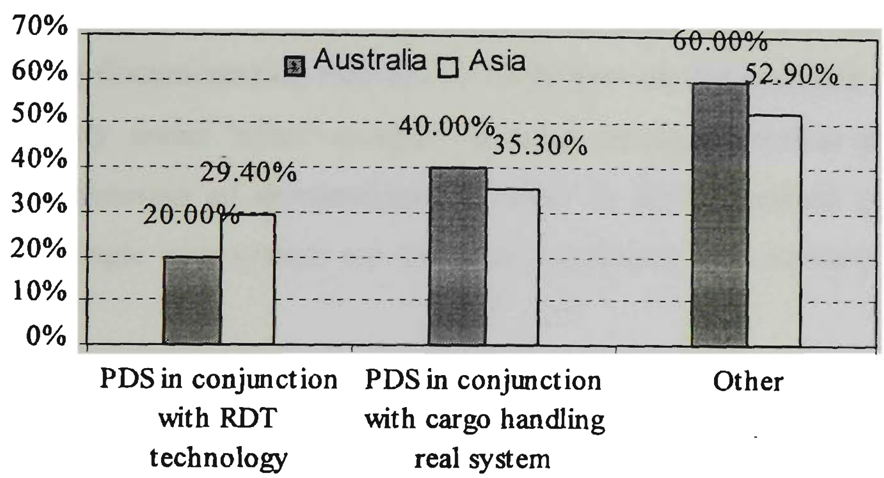


Figure 6.11. Technology used for tracking the movements of container within the stacking area.

6.6. Gate processes

Automatic methods of identifying road vehicles, containers and drivers are important at the entry gate of container terminals; there are three methods available: tags, bar codes and visual methods. Tags in the container terminal operation have two associated problems. Firstly, there is a lack of standards (Yates, 1994). Tags use a wide variety of radio frequencies and it is almost true to say that a tag reader of one manufacturer will not read the tag of any other manufacturer. The second problem is that tags represent a relatively large investment. Bar codes can give each container a unique specification, which enables its movements to be monitored wherever it may go. Identification by visual methods involves a closed circuit television (CCTV) to observe the trucks carrying containers into the terminal at entry gate.

The majority of terminals, 66.7% in Australia and 76.5% in Asia, are using other methods of identifying trucks carrying containers at gates (see Figure 6.12). However, at 50% of terminals in Australia the identification of trucks is done by the use of transponders. In the same figure, 17.6% terminals in Asia are using container recognition systems (CNRS). 16.7% terminals in Australia and 23.5% terminals in Asia are using CCTV for the identification of trucks. Under other category among Asian container terminals manual data entry, equipment interchange receipt (EIR), clerk, radio data terminals, access control system, swipe card, truck transaction reference (TTR), preadvice over the telephone, and truck driver having documentation relevant to containers are the methods used to identify the trucks. Similarly, under "other" category methods among Australian terminals manual and visual, pre-estimation of documentation, refers to documentation provided by the contractor, and a single gate system are the most commonly used methods to identify the trucks.

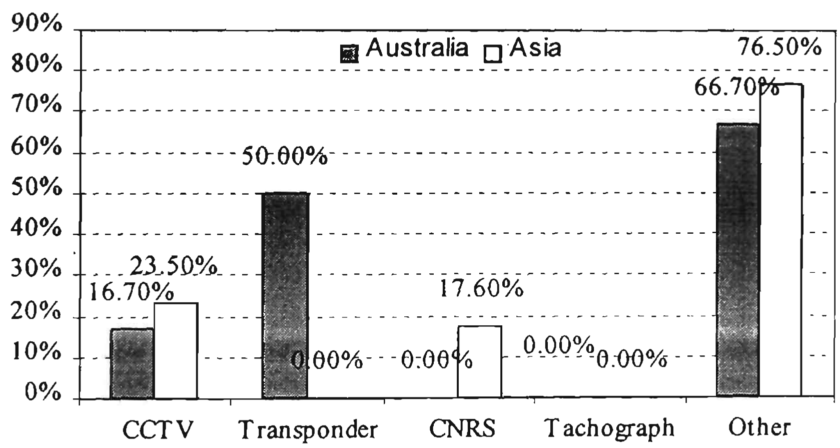


Figure 6.12. Comparison of methods used to identify the trucks at gate.

As Figure 6.13 shows, the majority of terminals in Australia, are accomplishing the booking of time-slot of road vehicles through on-line access to their systems. Bookings over the telephone and by facsimile are the second and third most used methods for Australian container terminals. In only one terminal (16.7%) in Australia is shift hours (open access) used. In Asia 38.5% of terminals are using other methods of booking the time-slot. Under this category, one terminal reported that telephone requests for servicing arranged outside regular hours. Three container terminals reported that they do not need booking. Two container terminals reported that booking is based on arrivals of trucks. However, booking through on-line access to the system is the least common (23.1%) among Asian container terminals.

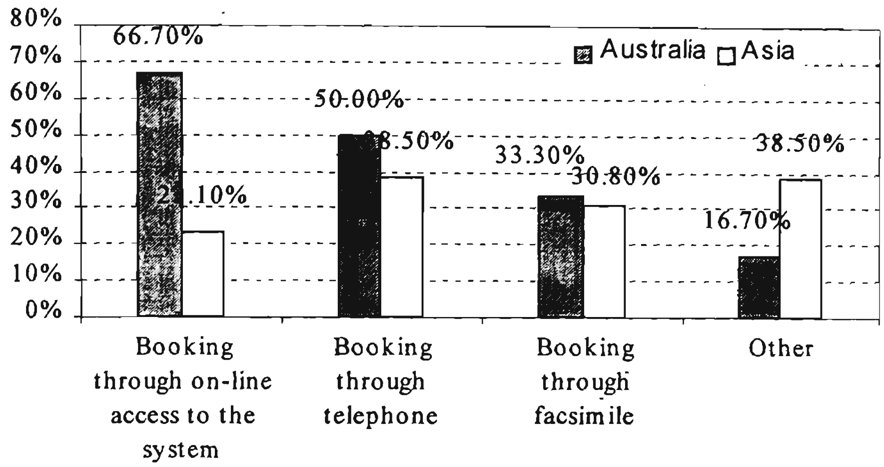


Figure 6.13. Comparison of the methods used to book the time-slot of road vehicles.

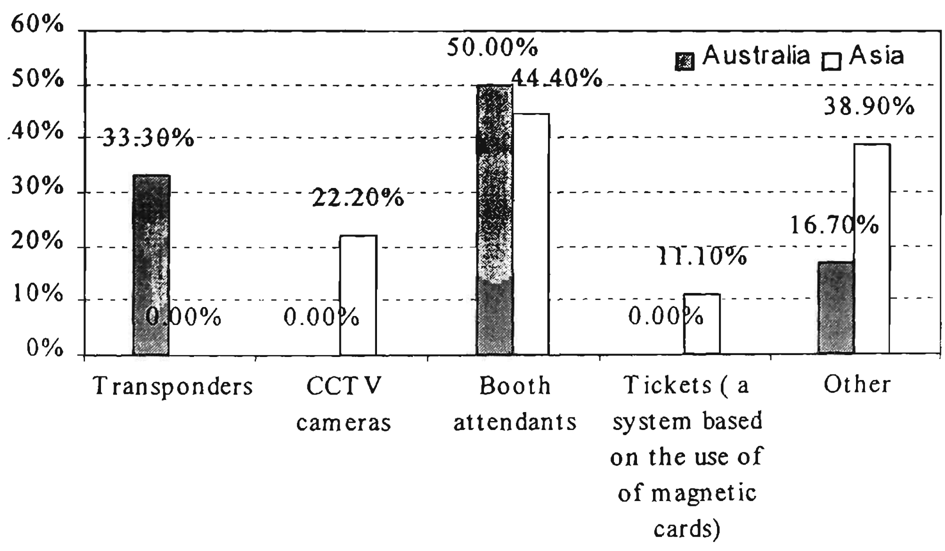


Figure 6.14. Characteristics of gate processes: driver identification methods at gate.

Figure 6.14 shows the methods used to identify the trucks in the terminal areas in Australia and Asia. Booth attendants (50.0%) and transponders (33.3%) are the first and second most used types of system used in Australia. One terminal in Australia is using BAT (e.g. a tiny device like a transponder) numbers to identify the trucks in terminals. In Asia 38.9% terminals are using number cards, manual and equipment operators, BAT numbers, with numbers and logos, and radio data terminals. Booth attendants and CCTV cameras are the first and second most widely used systems in Asia.

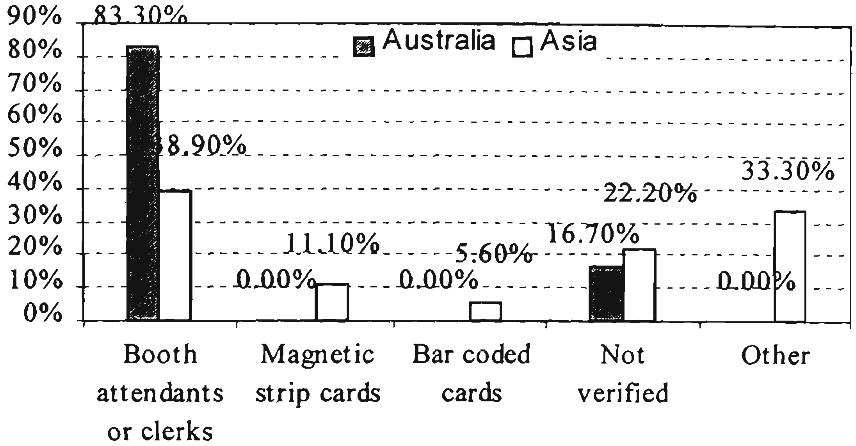


Figure 6.15. Characteristics of truck identification methods in the terminals.

At 83.3% of terminals in Australia booth attendants or clerks identify drivers, and in one terminal, the drivers' identities are not verified (see Figure 6.15). However, 33.3% of Asian terminals have different methods of identification of drivers such as ID card, license of driver, proximity cards, truck registration, equipment interchange receipt (EIR), access control system application, and contractor. From the same figure, at 22.2% of the terminals in Asia, the driver's identity is not verified. In some terminals in Asia the identification is achieved by using magnetic strip cards (11.1%) and bar coded cards (5.6%).

6.7. The use of electronic data interchange

All terminals reported having electronic data interchange (EDI) capabilities except 33.3% of terminals in Australia and 27.8% terminals in Asia. The representatives of the container terminals were asked to classify the level of EDI use in the processes of export and import containers. The responses are summarised in Figure 6.16. It can be seen that there is a low use of EDI among Asian terminals. On the other end of this graph, Asian terminals are not using EDI intensively.

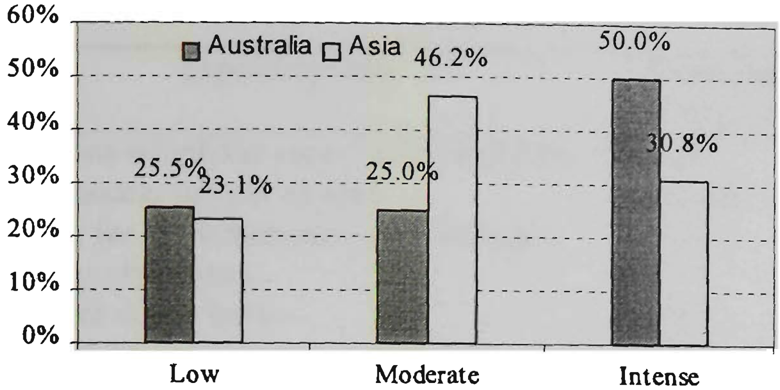


Figure 6.16. Intensity of use of EDI among Australian and Asian container terminals.

6.8. Information on container-status inquiry system

Container-status inquiry system is the on-line access to the container terminal pertaining to import containers arrival information. 33.3 percent of terminals in Australia do not have a container-status inquiry system against 12.5 percent in Asia (see Figure 6.17).

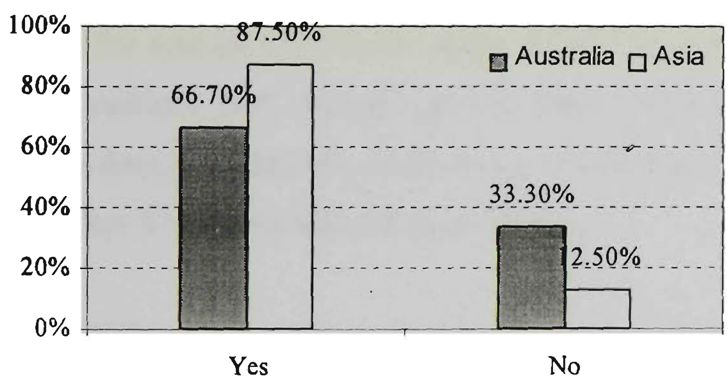


Figure 6.17. Comparison of container status inquiry systems.

On-line access to terminal systems appears to be the most popular (100.0%) in Australia in Table 6.4. However, among Asian terminals, 68.8% have on-line access to systems. Among Asian terminals 18.8% are planning to implement container inquiry status, 6.2% terminals in the project stage, and 6.2% terminals did not have one. The access hours vary: 6.00 am to 11.00 pm (7.7% in Asia), seven days a week (40% in Australia and 46.2% in Asia), 24 hours (100.0% in Australia and 53.80% in Asia), and other type (30.8% in Asia).

Table 6.4. Type of container inquiry systems.

Serial Number	Type of system	Percentage use in Australia	Percentage use in Asia
1	Touch tone telephone access to your system	0.0%	0.0%
2	On-line access to your system	100.0%	68.8%
3	Planning for implementation of container-status inquiry system	0.0%	18.8%
4	At present do not have	0.0%	6.2%
5	Project stage	0.0%	6.2%
6	Other	0.0%	18.8%

Under "other" type in Asia, one terminal has access hours during office hours, one terminal has access on appointment daily, and one terminal has 22 hours access a day only. However, the end users - transport companies (20.0%) in Asia seem to have low use of the system (see Figure 6.18). There may be a lack of awareness among transport companies in Asia for the potential benefits of container-status inquiry system and needs to be addressed with an aggressive policy. Similarly, in Asia railroad agents and brokers make the first and second lowest use of the system. 20.0% terminals in Asia reported that end users in their systems are banks, customs and internal private user. However, half of those who responded (50.0%) in Asia classified the level of use of container-status inquiry as low (see Figure 6.19) and another 31.2% classified it as moderate.

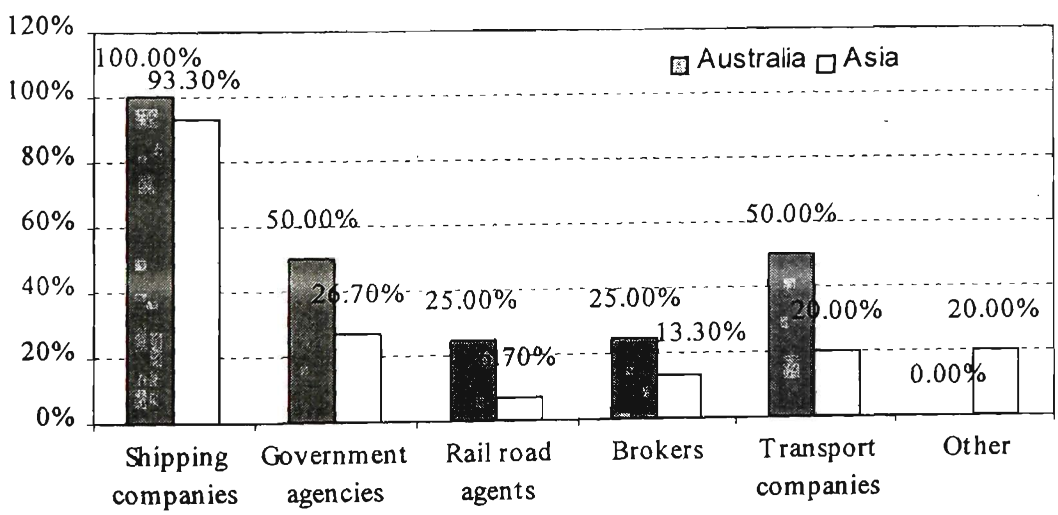


Figure 6.18. End users of on-line access to system in Australia and Asia.

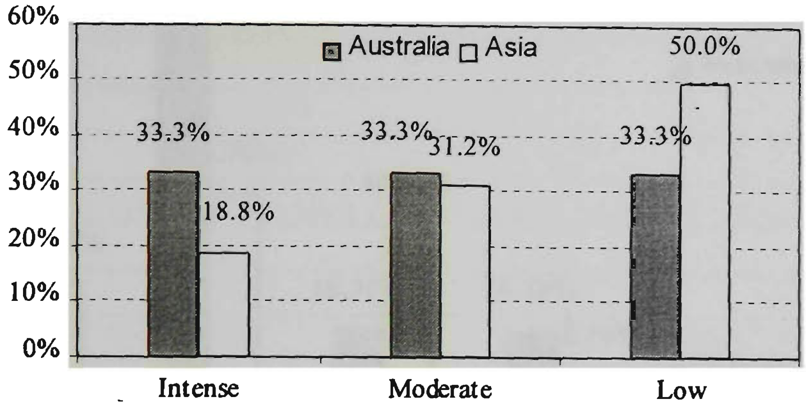


Figure 6.19. Level of use of information about container-status inquiry system in Australia and Asia.

6.9. Other interactions

A 'other interaction' is one that take place among the different agents associated with either importing or exporting containers. Releases sent manually are most widely used in Australia (83.3%) for release of freight followed by EDI (50.0%), by facsimile (16.7%), and by combination of EDI and facsimile (16.7%) as shown in Figure 6.20. In the same figure among Asian terminals, release sent manually, by facsimile, by EDI, and combination of EDI and facsimile are the first, second, third, and fourth most used methods. In contrast, in Asia the release of containers is performed by customs release instruction, on line entry, and by drivers having the appropriate documentation. However, only one case in Asia reported release is not of concern to the management.

In contrast, the transactions linking brokers to transport companies are performed by means other than EDI. According to survey brokers usually send bills of lading to motor carriers by messenger (50.0%) in Australia against 9.1% in Asia (see Figure 6.21).

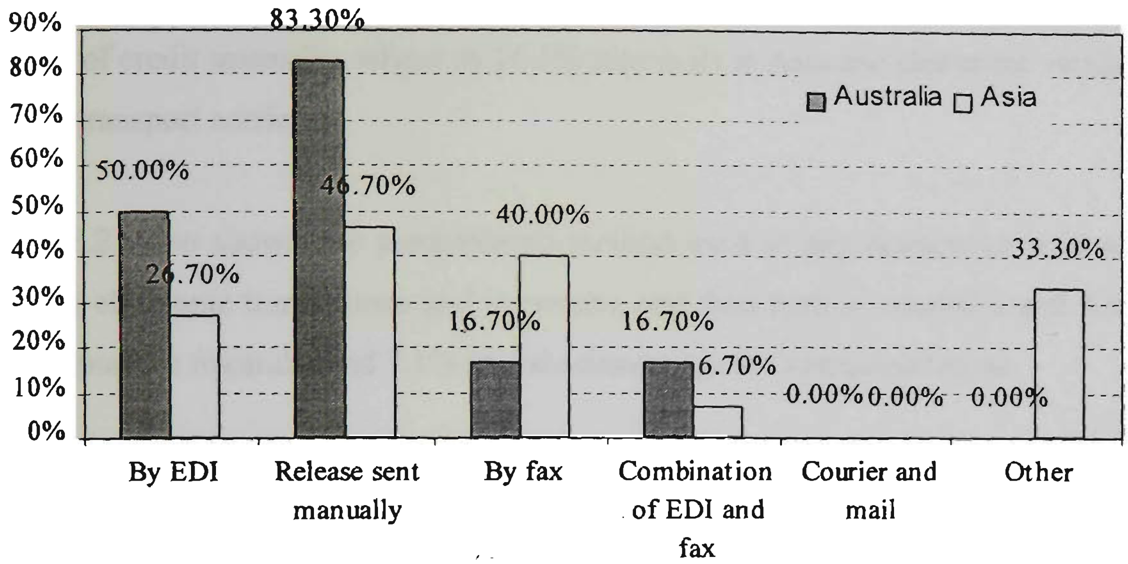


Figure 6.20. Methods used by terminals in Australia and Asia for the release of freight.

Among Asian container terminals facsimile (45.5%) and mail and courier services are the first and second most used methods used by brokers to send bills of lading to transport companies. In Asia, 36.4% terminals reported they have nothing to do with bills of lading and terminal operators verify only the documents carried by truck drivers.

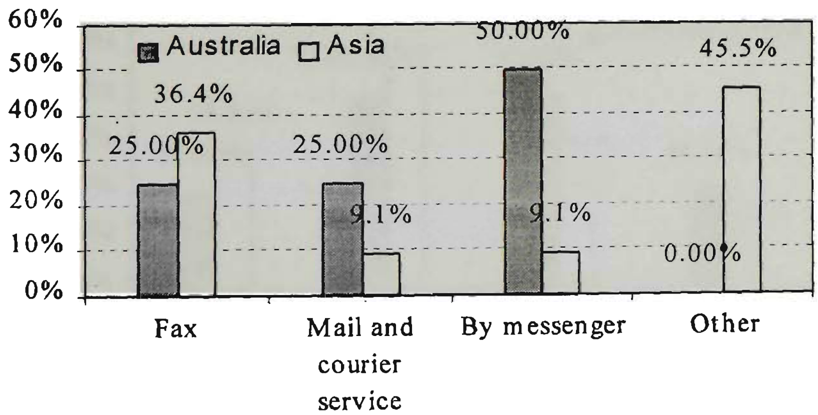


Figure 6.21. Technologies used by brokers to send bill of lading to transport companies in Australia and Asia.

IT can also be used for financial interactions. The survey indicated that there is room for such IT applications. Two activities of this type were considered in the survey: credit verification of transport carriers and payment of demurrage charges. In the survey terminals were asked to report the verification method of credit of transport carrier. Half of terminals of Australia reported that they do not verify credit against 28.6% in Asia (see

Figure 6.22). 33.3% terminals in Australia and 28.6% terminals in Asia reported the use of verification of credit manually, where as 14.3% terminals in Asia use electronic verification of credit of transport carrier.

As Figure 6.23 also shows, the predominant method used to pay demurrage is in person, followed by electronic transactions and in person, and then mail in Australia and Asia. In 20.0% terminals in Australia and 7.1% in Asia demurrage is not charged at all.

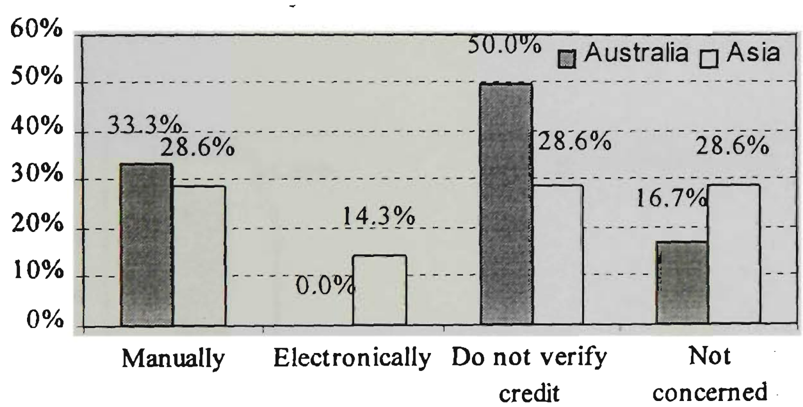


Figure 6.22. Credit verifications of transport carriers in Australia and Asia.

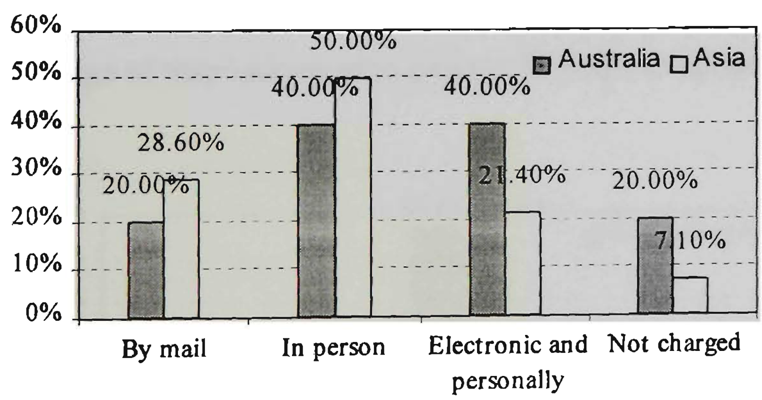


Figure 6.23. Methods used to pay demurrage in Australia and Asia.

6.10. Plans for the future adoption of information system

Terminals in Australia and Asia were asked information on the operators' perceptions of the future of IT. However, the questions used for this study were used from the questionnaire used by Kromberg (1988) and Holguín-Veras and Walton (1996b). Whilst Kromberg's survey targeted rail intermodal terminals and Veras and Walton's survey also targeted a selected group of US marine terminals, such a comparison is limited because the working environments are vastly different. The responses are shown in Figures 6.24, 6.25 and 6.26.

As Figure 6.24 shows, all terminals in Australia reported that IT would help to update container location in terminals against 94.4% in Asia, whereas in only one terminal reported conditional for use of IT in updating container location. Figure 6.25 shows that the majority of terminals in Australia and Asia agreed that radio frequency tags are not beneficial. However, 16.7% terminals in Australia and 27.8% terminals in Asia considered it to be beneficial.

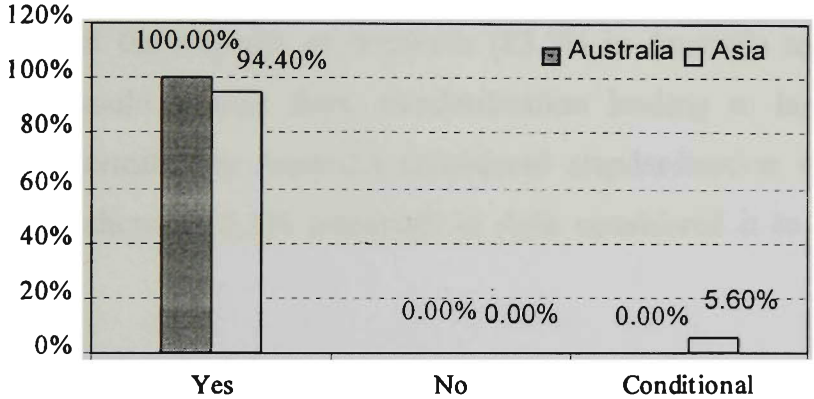


Figure 6.24. Percentage of respondents who believe IT helps to update container location.

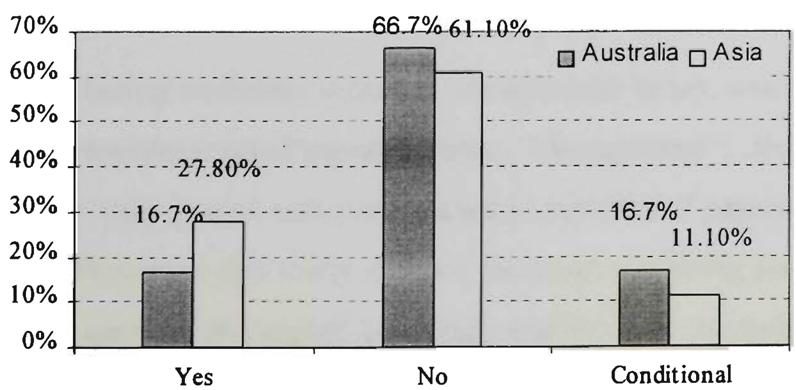


Figure 6.25. Percentage of terminals that use radio frequency tags.

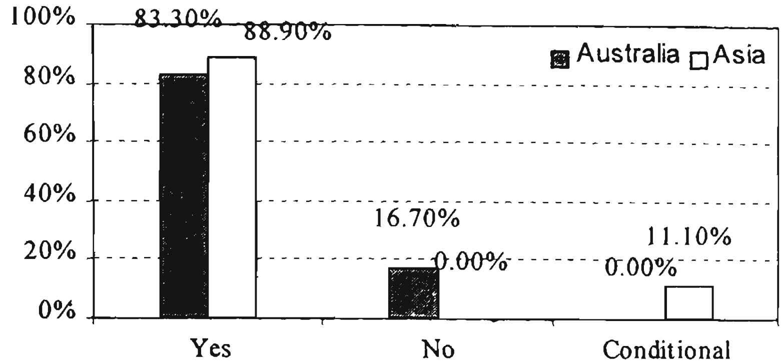


Figure 6.26. Percentage of container terminals that believe that standardisation leads to higher productivity.

Figure 6.26 shows that the majority of terminals (83.3% in Australia and 88.9% in Asia) consider that they would benefit from standardisation leading to higher productivity. However, only one terminal in Australia considered standardisation would not lead to higher productivity, whereas 11.1% terminals in Asia considered it to be of conditional help.

As these figures demonstrate almost all operators of container terminals believe that IT will play an important role in improving the efficiency of their operations.

6.11. Container handling equipment and automation

Of the many challenges facing container terminal management today, one of most critical is how best to manage the container handling equipment. Management's understanding of the current practice of IT in quay cranes and yard cranes is essential if capital resources are to be properly managed. However this study did not focus on analysing the options such as maintaining the status quo by managing container traffic with increasingly inadequate equipment, buying new cranes to expand their facilities and to replace ageing equipment, and refurbishment and modernisation of existing equipment.

However, 64.7% container terminals in Asia have quay cranes equipped with a crane management system, which provides operational, maintenance, fault diagnostic, and trouble-shooting facilities on board the cranes against 50% terminals in Australia (see

Figure 6.27). 33.3% in Australia and 23.5% in Asia did not have crane management systems. Only one terminal in Asia is planning to implement such a system in future. However, one terminal in Australia has limited use of this system, whereas one terminal in Asia has these facilities in some quay cranes.

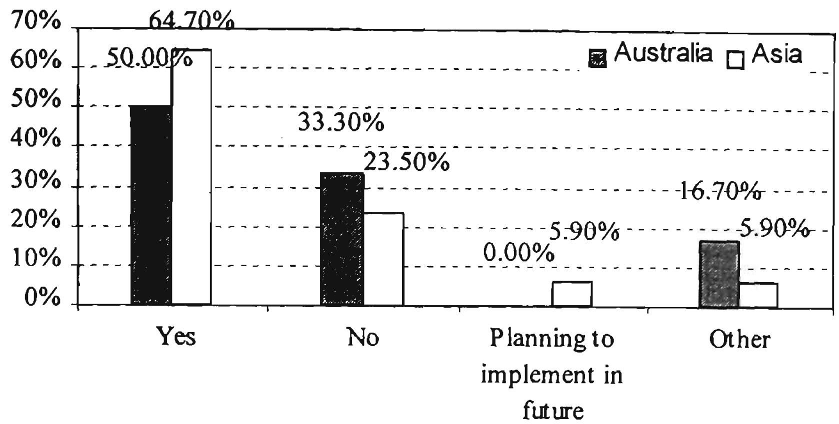


Figure 6.27. Percentage of quay cranes in Australia and Asia equipped with a crane management system.

Terminal operators were asked whether the yard cranes used in their terminals were out dated or modern technology. The majority of container terminals (76.5% in Asia and 75.0% in Australia) have reported the use of modern technology for yard cranes. Only 25% terminals in Australia and 23.5% terminals in Asia are using out dated technology. Table 6.5 provides the type of system used such as crane management system, automatic positioning indicating system, digital drive system, and automatic control system to facilitate semi-automatic mode of operation in yard cranes. It shows that crane management systems are more widely used in Asia as than in Australia. Another 33.3% of terminals in Australia are using straddle carriers. Where as in 15.4% terminals in Asia, one terminal is using semi automatic, one terminal using NOELL make gantry cranes (built in 1998) and other one is using all the above for rail mounted cranes and crane management system and PDS for rubber tyred cranes.

Table 6.5. The types of the system used to monitor the operation of yard cranes in Australia and Asia.

Serial number	Type of system to monitor the operation of yard areas	Percentage use in Australia	Percentage use in Asia
1	Digital drive system	0.0%	23.1%
2	Crane management system	33.3%	46.2%
3	Automatic position indicating system	33.3%	7.7%
4	Automatic travel control system to facilitate semi-automatic mode of operation	0.0%	23.1%
5	All the above	33.3%	7.7%
6	Other	33.3%	15.4%

However, 52.9% of container terminals in Asia reported the automation of equipment would change productivity whereas one terminal in Australia considered it would not change the productivity. Half of the terminals in Australia and Asia considered that automation would lead to higher productivity.

All container terminals were asked to choose the ways they would prefer to automate equipment. Responses are summarised in Table 6.6. It can be seen that 62.5% terminals in Asia would prefer electronic positioning in container terminal. However, in Australia 66.7% terminals prefer to improve by any reasonable means whereas 33.3% terminals prefer electronic positioning of container terminals to facilitate automation. One terminal reported that it prefers automated straddles.

Table 6.6. Percentage of preference for automation of equipment in Australia and Asia.

Serial number	Preference for equipment automation	Percentage use in Australia	Percentage use in Asia
1	Electronic positioning of container terminal	33.3%	62.5%
2	Automatic steering for rubber-tyred gantry crane	0.0%	31.2%
3	Phased introduction of automated handling system so as to minimise operating costs	0.0%	31.2%
4	Improve by any reasonable means the standard provided to shipping lines and to their customers	66.7%	50.0%
5	Other	16.7%	0.0%

Most of the terminals in Australia (83.3%) and Asia (77.8%) are using computers for storage planning and storage yard operation whereas 11.1% in Asia are planning to implement it in future (see Figure 6.28). In one case in Australia computers are not used for storage planning and yard operation against two terminals in Asia.

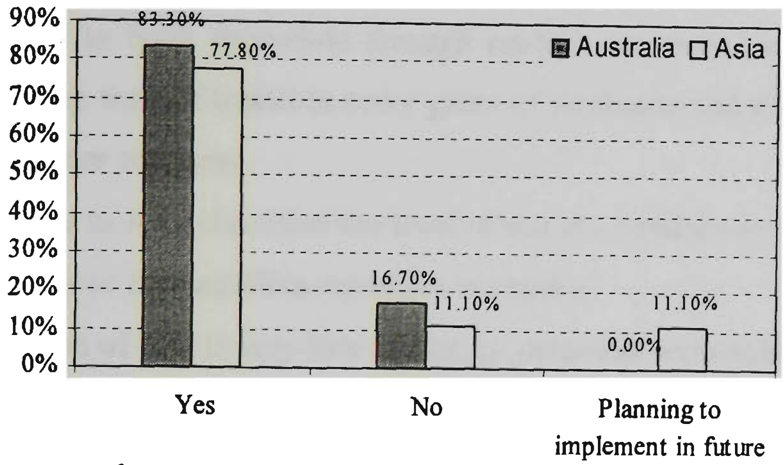


Figure 6.28. Comparison of use of computers for planning the storage of containers in yards and the operation of yards in Australia and Asia.

6.12. Conclusions

The introduction of information systems and information technology into the container handling operations during the current decade has brought about significant advantages in terms of speed, efficiency and cost reductions. However, the application is limited to larger capacity terminals. Half the terminals in Australia whose handling capacity is less than 10 000 TEUs per month do not have modern computing technology. Similarly, one sixth of terminals which participated in this study in Asia also do not have a computer-integrated operating system. It is clear that there is considerable amount of scope for implementation of more sophisticated management information systems for smaller terminals when the need arises. However, the conclusions are limited by the small sample size from Australia and Asia but they may be stated as follows:

- Automatic equipment identification technology is presently not installed in all terminals located in Australia in Australia and Asia.

- Fourteen different agents more or less involved in container terminal activities have been identified. However, in Asia, container terminals are not involved in any interactions with trading banks.
- Booking through on-line access to the system is least widespread among Asian container terminals. Significant services to transport carriers can be improved by allowing carriers to book time-slots through on-line access to the system. This can reduce the waiting time of trucks at entry gates of terminals and the terminal operators can guarantee better services.
- Half the terminals in Asia classified the level of use of container-status inquiries are low compared with those in Australian container terminals.
- Intense application of EDI is very low among all container terminals in Asia.
- 83.3% container terminals in Australia are using a manual method of freight release process.
- All the terminals reported that IT could help to update container location in yard areas.
- More than half the terminals in Australia and Asia reported not wanting to use radio frequency tags in future.
- In Australia half the terminals reported quay cranes are not linked to modern crane management system.
- More than 80% of container terminals in Australia and Asia agree that the benefit from standardisation of container location leads to higher productivity.

Taking full advantage of modern management information systems requires the active participation and integration of all fourteen parties involved in container terminal operation and should be considered a primary policy goal of the management. Because labour costs are rising and container sizes as well as complexity of problems are increasing, the productivity of container terminals must improve. The information flows among fourteen parties dealing with container terminals should be investigated to understand the scope for integration of information system and information technology in future.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

7.1. Conclusions

The throughput of container terminals measured in TEUs has grown at an annual rate 9.5% in Australia between 1998/99 and 1997/98 (BTE, 1999). Container terminals are conduits through which high added value products are imported or exported. It is essential that these conduits offer as little constriction as possible to the smooth flow of goods through them. The research presented in this thesis explores several facets of the management of container terminals. The principal conclusions are:

- There are no universally agreed performance indicators for container terminals. Responses to a questionnaire sent to operators of container terminals in Australia and Asia highlighted that operators use a hideous melange of deductions to calculate the vessel and quay crane productivity of terminals. They appear to choose, almost at random, from a list of deductions that comprises delays in boarding vessel, completion-to-sailing time, no labour rostered, and port-wide industrial disputes in their estimations of elapsed labour time. Similarly other deductions that comprise eleven delays including quay crane boom up/down for other passing vessels, award shift breaks, delays caused by the vessel, smoke/meal breaks, handling break-bulk cargo, ramp work for RO RO vessels, rostered labour withheld, handling vessels' hatch lids, delays caused by need for cages, conlocking and lashing work, and weather related delays for estimate of gross service time of vessel. Managers of individual terminals have unique deductions for calculation of net crane hours that comprise delays caused by the vessel, crane boom up/down for other vessels, smoke/meal breaks, handling break-bulk cargo, long travel moves of cranes from one vessel to another, crane break down, and weather related delays.

- Simulation allowed some novel approaches to the management of West Swanson container terminal to be investigated. The value of the different approaches has been quantified. The input data were collected as part of this research, and the raw data were subsequently expressed in terms of probability density functions. The model has been validated by comparing predicted results with experimental data. Output from the model was generalised by means of a response surface methodology. The simulation model can be used as a platform from which other container terminals can be investigated.

- The model has been used to explore the performance of the landside operations of a container terminal. It is shown that a minimum turnaround time of trucks can be achieved using 5 gates, 14 grids in the North Park, and 9 grids in the South Park without any change in present throughput (883 trucks per day). An increase of 30% in the arrival rate of trucks improves daily throughput by an average of 126 trucks; however a further increase in arrival rate seems to have no significant effect on the daily throughput. The extra trucks are unable to enter the terminal and the lengths of queues increased. A throughput of 1124 trucks can be achieved with a 30% increase in arrival rate of trucks and a 50% decrease in processing time on grids to achieve an average turnaround time of 21.8 minutes at the present set-up.

- An increase of straddle carriers from 6 to 7 under the present set-up improves daily throughput by an average of only 13 containers per day. But an increase of straddles to 7 is expected to have a profound effect on reducing the average waiting time of trucks on grids from 16.58 minutes to 8.86 minutes, a decrease of 46.5%. However, a further increase of straddle carriers results in no further increase in daily throughput of containers. The proposed heuristic job assignment rule for straddles was tested in this study. The results indicates that both present job assignment (preferred order) and proposed job assignment (smallest distance to station) rules performed equally well on average container flow time, daily throughput, average waiting time of jobs, number of jobs in the queue for service by straddles, and straddle utilisation. Therefore, a proposed heuristic job assignment rule cannot be considered for implementation. Maintaining a higher speed of straddle carriers (> 16 km/hr) can achieve better performance in the present set-up. However, maintaining higher speeds by the straddle carriers in the present set-up is not possible due to restricted routes and traffic congestion raised due to the operations of the seaside straddle carriers. One more straddle carrier can be deployed in addition to the 6 existing straddle carriers in order to reduce the truck waiting time on grids further and lower straddle carrier utilisation.

- Management information systems play an ever-increasing role in the operation of container terminals. Results from a survey of container terminal operators in Australia and Asia show that the implementation of information technology is limited to larger capacity terminals. Automatic equipment identification technology is presently not installed in all terminals located in Australia and Asia. Booking through on-line access to the system is least wide spread among Asian container terminals. More than half the terminals in Australia and Asia reported not wanting to use radio frequency tags in future. More than 80% of terminals in Australia and Asia agree that the benefit from standardisation of container location in yards leads to higher productivity.

7.2. Recommendations for future research

The components of the research reported in this thesis have been taken to a high degree of completion, however whilst carrying out the research several aspects of the operation of container terminals have emerged that are worthy of further research. These include:

- The vessel and quay crane performance related delays used for calculating the net rates differ from one terminal operator to the next. The underlying differences pertaining at each of container terminal must be investigated before deduction factors can be standardised.

- It is very difficult to model all aspects of a container terminal operation because of the complexity of the system. There are thousands of containers, each with different characteristics such as container port destination, size, weight and type; in effect, existing industrial simulation software packages are not yet fully satisfactory for yard space management. Especially, storage locations of export and import containers affect significantly the distances that straddle carriers have to travel. This problem is more complex when the space available for storage of containers is limited, as it is in most terminals and expansion of yard blocks is usually expensive or often impossible. A more detailed simulation model is required to study the best use of yard space and effect of container dwell time on throughput.

- An efficient vessel loading and unloading operation depends on the number of quay cranes available, quay crane assignment policies, working rates of quay cranes, the number of straddle carriers for each quay crane for transporting containers to or from the vessel, shift hours, yard space, and berth length. The problem of optimal loading and unloading of vessels is very difficult to solve, because the resolution of real loading problems is even more complex than unloading since the final place of each container, the used resources, and container loading sequence have to be decided. For solving this problem more simulation work is required to study the effect of these factors on terminal throughput. Methods based on advanced optimisation techniques can be explored for finding optimal loading and unloading of the vessel.

- Chapter 6 focused on the most relevant activities of container terminal operators in Australia and Asia in the context of information systems (IS) and information technology (IT). However, this thesis does not include the activities of 14 identified agents with terminal operators in terms of its activities. For example, whether trucking companies are successfully integrating with terminals that have an IT environment. The detailed examination of all the activities of linking agents with container terminals and activities performed within each agent should be investigated. Taking full advantage of the possibilities of IS and IT requires the active participation and integration of all 14 agents that have been identified.

References

Absalom, A. (1992), "Shipper-carrier information integration using EDI", *World Freight Technology `92*, The annual review of land, sea and air freight handling systems, edited by James Abbott, Sterling Publications International Limited, London, UK, pp. 127-129.

Anon. (1998), "Simulation software buyer's guide", *IIE Solutions*, vol. 30(5), pp. 48-54.

ARENA user's guide with version 3.0 (1996), System Modelling Corporation, Sewickley, PA, USA.

ARENA user's guide with version 3.5 (1998), System Modelling Corporation, Sewickley, PA, USA.

Ashar, A. (1985), "Productivity and capacity of container terminals", *World Wide Shipping*, vol. 48(5), pp. 73-76.

Balci, O. (1995), "Principles and techniques of simulation validation, verification, and testing", *Proceedings of the 1995 Winter Simulation Conference*, edited by C. Alexopoulos, K. Kang, W. R. Lilegdon, and D. Goldsman, Arlington, VA, pp. 147-154.

Ballis, A. and Abacoumkin, C. (1996), "A container terminal simulation model with animation capabilities", *Journal of Advanced Transportation*, vol. 30(1), pp. 37-57.

Banks, J. (1996), "Output analysis capabilities of simulation software", *Simulation*, vol. 66(1), pp. 23-30.

Banks, J. and Gibson, R. G. (1997), "Selection of simulation software", *IIE Solutions*, vol. 29(5), pp. 30-32.

Barr, D. (1993), "Improving road haulage turnaround times", *World Freight Technology*, The annual review of land, sea and air freight handling systems, edited by James Abbott, Sterling Publications International Limited, London, pp. 63-65.

Barton, R. R. (1992), "Metamodels for simulation input-output relations", *Proceedings of the 1992 Winter Simulation Conference*, edited by J. Swain, David Goldsman, Robert C. Crain, and James R. Wilson, NJ, USA, pp. 289-299.

Beemen, O. and Vallicelli, G. (1975), "Specifications for container facilities by simulation", *Symposium on Modelling Techniques*, Modelling, vol. 1, pp. 75:23-42.

Berg, J. (1998), *Maritime Logistics I: Transporting Cargo by Sea*, edited by Frank Cecconi, Australian Food Marketing Centre, Victoria University of Technology, Melbourne.

BIE (Bureau of Industry Economics) (1993), *International Performance Indicators – Waterfront Australia*, Research Report 47, Australian Government Publishing Service, Canberra.

Blanning, R. W. (1975), "The construction and implementation of metamodels", *Simulation*, vol. 24, pp. 177-184.

Box, G. E. P. and Draper, N. K. (1987), *Empirical Model Building and Response Surfaces*, John Wiley and Sons, New York, USA.

Box, G. E. P., Hunter, W. G., and Hunter, J. S. (1978), *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building*, John Wiley & Sons, New York.

Bozer, Y. A. and Srinivasan, M. M. (1991), "Tandem configurations for automated guide vehicle systems analysis of single vehicle loops", *IIE Transactions*, vol. 23(1), pp. 71-82.

Bruzzone, A and Signorile, R. (1998), "Simulation and genetic algorithms for ship planning and shipyard layout", *Simulation*, vol. 71(2), pp. 74-83.

BTCE (Bureau of Transport and Communications Economics) (1995), *Adequacy of Transport Infrastructure Sea Ports*, Working Paper 14.3, Canberra, Australia, pp. 35-37.

BTCE (Bureau of Transport and Communications Economics) (1996), *Waterline*, Issue No. 6, Canberra.

BTE (Bureau of Transport Economics) (1985), *Container Terminal Productivity in Port Botany: CTAL Terminal*, Occasional Paper 70, Australian Government Publishing Service, Canberra.

BTE (Bureau of Transport Economics) (1999), *Waterline*, Issue No. 20, Canberra.

Choi, H., Kwon, H., and Lee, J. (1994), "Traditional and tandem AGV system layouts: a simulation study", *Simulation,* vol. 63(2), pp. 85-93.

Conover, W. J. (1980), *Practical Nonparametric Statistics*, Second edition, John Wiley & Sons, Inc., New York.

Colebatch, T. (1997), "Strike losses lead to waterfront's latest verbal war", *The Age*, 17th February, Melbourne, p. 5.

Colebatch, T. (1998), "Ports too costly and slow: report", *The Age*, 28th April, Melbourne, p. 6.

Draper, N. R. (1982), "Center points in second-order response surface designs", *Technometrics*, vol. 24, pp. 127-133.

Draper, N. R. and Smith, H. (1981), *Applied Regression Analysis*, Second edition, John Wiley & Sons, Inc., New York, pp. 129-133.

Egbelu, P. J., and Tanchoco (1988), "Characterization of automatic guided vehicle dispatching rules", *International Journal of Production Research*, vol. 22(3), pp. 359-374.

Evers, J. J. M. and Koppers, S. (1996), "Automated guided vehicle traffic control at a container terminal", *Transportation Research-A, Police and Practice*, vol. 30(1), pp. 35-40.

Farrington, P. A. and Swain, J. J. (1993), "Design of simulation experiments with manufacturing applications", *1993 Winter Simulation Conference Proceedings*, Los Angeles, California, edited by G. W. Evans, M. Mollaghasemi, E. C. Russel, and W. E. Biles, pp. 69-75.

Gambardella, L. M., Bontempi, G., Taillard, E., Romanengo, D., Raso, G., and Piermari, P. (1996), "Simulation and forecasting in intermodal container terminal", Simulation in Industry, *8th European Simulation Symposium*, Genoa, Italy, pp. 626-630.

Gambardella, L. M., Rizzoli, A. E., and Zaffalon, M. (1998), "Simulation and planning of an intermodal container terminal", *Simulation*, vol. 71(2), pp.107-116.

Goldsman, D. (1992), "Simulation Output Analysis", *Proceedings of the 1992 Winter Simulation Conference*, edited by J. Swain, David Goldsman, Robert C. Crain, and James R. Wilson, NJ, USA, pp. 97-103.

Halliday, D. and Resnick, R. (1988), *Fundamentals of Physics*, John Wiley & Sons, New York.

Hayuth, Y., Pollatschek, M. A., and Roll, Y. (1994), "Building a port simulator", *Simulation*, vol. 63(3), pp. 180-189.

Hedrick, R. L. and Akalin, M. T. (1989), "Simulation modelling of marine container terminal facilities and their operation", *21st Century-ship and offshore ship design, construction and operation, ship technology and research symposium*, New Orleans, LA, USA, pp. 720-729.

Hoover, S. V. and Perry, R. F. (1990), *Simulation A Problem-Solving Approach*, Addison-Wesley Publishing Company, Inc., USA.

Holguín-Veras, J. and Walton, C. M. (1996a), "On the development of a computer system to simulate port operations considering priorities", *Proceedings of the 1996 Winter Simulation Conference*, edited by J. M. Charnes, D. J. Morrice, D. T. Brunner, and J. J. Swain, Piscataway, N.J., pp. 1471-1478.

Holguín-Veras, J. H. and Walton, C. M. (1996b), "State of the practice of information technology at marine container ports", *Transportation Research Record* (report no 1522), Washington, pp. 87-93.

Hutchins, J. L. and Akalin, M. T. (1995), "Use of simulation models at container and bulk liquid terminal facilities", *Proceedings of the Ports' 95 Conference*, PIANC, Florida, vol. II, pp. 665-676.

Kelton, W. D. (1996), "Statistical issues in simulation", *Proceedings of the 1996 Winter Simulation Conference*, edited by J. M. Charnes, D. J. Morrice, D. T. Brunner, and J. J. Swain, Piscataway, N.J., pp. 47-53.

Kelton, W. D., Sadowski. R. P., and Sadowski, D. A. (1998), *Simulation with Arena*, McGraw-Hill, New York.

Kleindorfer, G. B. and Ganeshan, R. (1993), "The philosophy of science and validation in simulation", *Proceedings of the 1993 Winter Simulation Conference*, edited by G. W. Evans, M. Mollaghasemi, E. C. Russel, and W. E. Biles, Los Angeles, California, pp. 50-57.

Koh, P., Ng, H., Ng, H., and Goh, J. L. K. (1994), "Using simulation to preview plans of a container port operations", *Proceedings of the 1994 Winter Simulation Conference*, USA, edited by J. D. Tew, S. Manivannan, D. A. Sadowski, and A. F. Seila, pp. 1109-1115.

Kondratowicz, L. J. (1990), "Simulation methodology for intermodal freight transportation terminals", *Simulation*, vol. 55(1), pp. 49-57.

Kozan, E. (1997), "Increasing the operational efficiency of container terminals in Australia", *Journal of Operational Research Society*, vol. 48(2), pp. 151-161.

Kromberg, P. N. (1988), "Transportation Research Circular 332: Automatic Equipment Identification Systems for Intermodal Operations", *A Railroad perspective*, TRB, National Research Council, Washington, D. C., USA.

Lacey, H. (1980), "The interrelationship of terminal design and equipment selection", *Intermodal Containerization and Marine Terminal Development Conference*, ICHCA USA, New York, pp. 214-223.

Law, A. M. (1986), "Introduction to simulation: a powerful tool for analysing complex manufacturing systems", *Industrial Engineering*, vol. 18, pp.46-63.

Law, A. M. (1990), "Models of random machine downtimes for simulation", *Proceedings of the 1990 Winter Simulation Conference*, edited by Osman Balci, Randall P. Sadowski, and Richard E. Nance, New Orleans, Louisiana, pp. 314-316.

Law, A. M. and Kelton, W. D. (1991), *Simulation Modeling and Analysis*, Second edition, McGraw-Hill, Inc., New York, USA.

Lee, J., Choi, R. H., and Khaksar, M. (1990), " Evaluation of automated guided vehicle systems by simulation", *Computers and Industrial Engineering*", vol. 19(1-4), pp. 318-321.

Lee, J. (1996), "Composite dispatching rules for multiple-vehicle AGV systems", *Simulation*, vol. 66(2), pp. 121-130.

Madu, C. N. and Kuei, C. (1993), *Experimental Statistical Designs and Analysis in Simulation Modelling*, Quorum Books: Westport, USA.

Mahadevan, B. and Narendran (1990), "Design of an automated guided vehicle-based material handling system for a flexible manufacturing system", *International Journal of Production Research*, vol. 28(9), pp. 1611-1622.

Maxwell, W. L. and Muckstadt, J. A. (1982), "Design of automated guided vehicle systems", *IEE Transactions*, vol. 14(2), pp. 114-124.

McGovern, P. (1988), "Port performance indicators", *Proceedings of the 2nd Australian Port, Harbour and Offshore Engineering Conference*, Brisbane, 25-27 October, pp. 16-25.

McHaney, R. (1991), *Computer Simulation A Practical Perspective*, Academic Press, Inc., San Diego, California, USA.

Melessen, H. K. J. (1969), "Managerial tools for improving productivity", *Proceedings of the 9th International Conference of the International Cargo Handling Co-ordination Association*, London, pp. 70-81.

Merkuryev, Y., Tolujew, J., Blümel, E., Novitsky, L., Ginters, E., Viktorova, E., Merkuryeva, G., and Pronins, J. (1998), "A Modelling and Simulation Methodology for Measuring the Riga Harbour Container Terminal", *Simulation*, vol. 71(2), pp. 84-95.

Monie, G. D. (1987), *Measuring and Evaluating Port Performance and Productivity*, UNCTAD Monographs on Port Management, No. 6, UN, Geneva

Montgomery, D. C. (1997), *Design and Analysis of Experiments*, John Wiley & Sons, New York.

Mosca, R., Giribone, P., and Bruzzone, A. G. (1994), "Simulation and automatic parking in a training system for terminal container yard management", *Proceedings of the 5th International Training Equipment Conference and Exhibition*, April, The Hague, pp. 434-443.

Nevins, M. R., Macal, C. M., Love, R. J., and Bragen, M. (1998), "Simulation, animation and visualization of seaport operations", *Simulation*, vol. 71(2), pp. 96-106.

Newton, D. (1985), "Simulation model calculates how many automated guided vehicles are needed", *Industrial Engineering*, vol. 17(2), pp. 68-73.

PC (Productivity Commission) (1998a), *International Benchmarking of the Australian Waterfront*, Ausinfo, Canberra.

PC (Productivity Commission) (1998b), *Work Arrangements in Container Stevedoring*, Ausinfo, Canberra, pp. 12-17.

PDI (1988), "Simulation - you can take the real thing", *Port Development International*, October, pp. 20-25.

Pegden, C. D., Shannon, R. E., and Sadowski, R. P. (1995), "*Introduction to simulation using SIMAN*", Second edition, McGraw-Hill, Inc., New York, USA.

Pulat, P. S. and Pulat, B. M. (1989), "Throughput analysis in an automated material handling system", *Simulation*, vol. 52(5), pp. 195-198.

Ramani, K. V. (1996), "An interactive simulation model for the logistics planning of container operations in seaports", *Simulation*, vol. 66(5), pp. 291-300.

Robinson, R. (1985), "Productivity of first-generation container terminals: Sydney, Australia", *Maritime Policy and Management*, vol. 12(4), pp. 279-292.

Robinson, R. and Reyes, J. M. (1984), "ASEAN and Australian Ports: Some Aspects of Efficiency and Productivity in the Early 1980s",. *Handmaiden of Trade: A Study of ASEAN Australian Shipping*, edited by K. Trace, Chia Lin Sien, F. Gallagher and Shahril Hj. Abd Karim, (Singapore University Press, 1988), pp. 113-144.

Robinson, S. (1994), *Successful Simulation A Practical Approach to Simulation Projects*, McGraw-Hill Book Company, London, UK.

S + DOX^{TM} design of experiments user's manual, Version 1.0, May 1994, MathSoft, Inc, Seattle, Washington.

Sargent, R. G. (1982), "Verification and validation of simulation models", Chapter IX in *Progress in Modelling and Simulation*, edited by F. E. Cellier, Academic Press, London, pp. 159-169.

Sargent, R. G. (1984), "Simulation model validation", *Simulation and Model-Based Methodologies: An Integrative View,* edited by Oren, et al., Springer-Verlag.

Sargent, R. G. (1996), "Verifying and validating simulation models", *Proceedings of the 1996 Winter Simulation Conference*, edited by J. M. Charnes, D. J. Morrice, D. T. Brunner, and J. J. Swain, Coronado, CA, pp. 55-64.

Shannon, R. E. (1981), "Tests for the verification and validation of computer simulation models", *Proceedings of the 1981 Winter Simulation Conference*, pp. 573-577.

Stempel, A. (1991), "Terminal wonder-land with SCUSY", *Cargo Systems*, May, pp. 81-83.

Stirling, A. H. C. (1989), "Increasing automation in UK ports", *Journal of the Dock and Harbour Authority*, London, vol. 70(814), pp. 207-209.

Suykens, F. (1983), "A few observations on productivity in seaports", *Maritime Policy and Management,* vol. 10(1), pp. 17-40.

Swain, J. J. (1997), "Simulation goes mainstream", *OR/MS Today*, vol. 24(5), pp. 35-46.

TCS (Thomson Clarke Shipping) (1997), *International Benchmarking Study of the Australian Waterfront*, Part: A Report, August, Melbourne.

Teo, Y. M. (1993), "Simulation and graphics animation in port design", *Proceedings of the 1993 European Simulation Multiconference*, Lyon, France, pp. 520-527.

Tew, J. D. (1992), "Using central composite designs in simulation experiments", *Proceedings of the 1992 Winter Simulation Conference*, Institute of Electrical and Electronics Engineers, Washington, D. C., pp. 529-538.

Trade & Transport Review, 1996/97, Melbourne Port Corporation, Melbourne, Victoria.

Trade & Transport Review, 1997/98, Melbourne Port Corporation, Melbourne, Victoria.

Vandeveer, D. (1998), "Port productivity standards for long-term planning", *Proceedings of the Ports' 98 Conference*, March, Long Beach, CA, USA, pp. 79-88.

Vincent, S. (1998), "Input Data Analysis", *Handbook of Simulation Principles, Methodology, Advances, Applications, and Practice*, edited by Jerry Banks, John Wiley & Sons, Inc., New York, Chapter 3, pp. 55-91.

Vining, G. G. (1998), *Statistical Methods for Engineers*, Duxbery Press, Pacific Grove, CA, USA.

Walker, R. L. and Helmick, J. S. (1998), "Port access and productivity: a systems approach", *Proceedings of Ports' 98 Conference*, Long Beach, CA, USA, pp. 720-729.

Ward, T. (1995), "Simulation analysis for planning Deltaport container terminal, Vancouver, B.C.", *Proceedings of the Ports' 95 Conference*, PIANC, Florida, vol. II, pp. 640-651.

Ward, T. (1998), "New ideas for increasing wharf productivity", *Proceedings of the Ports' 98 Conference*, Long Beach, CA, USA, pp. 69-78.

Yates, B. (1994), "Container yard automation systems", *World Freight Technology `94*, The annual review of land, sea and air freight handling systems, edited by James Abbott, Sterling Publication International Limited, London, UK, pp. 103-106.

APPENDIX A

fax: T. Blood 27/7/98

P&O Ports

P&O Ports Limited
A.C.N. 000 049 301
MacKenzie Road
FOOTSCRAY VIC 3011
GPO Box 4732
Melbourne Vic 3001
Telephone: +61 3 9687 4266
Facsimile: +61 3 9687 4640

Memorandum

To: CHRIS VICARY

From: RON BEATTIE

Copy to: Michael Povazan
Fred Lucas
Jyotirmaya Behera
Graham Thorpe
Chandra Bhuta

Date: 24 July 1998

Reference: **OPERATIONAL RESEARCH STUDY OF WEST SWANSON CONTAINER TERMINAL**

The overall objective is to achieve a model that is based upon integration of our three main working areas within the West Swanson Container Terminal (Ship, Yard, & Road). Although these three areas can and should be analysed separately, the final model should integrate all areas, to establish flow-on effects and benefits between and within these work areas.

The study and resultant model should aim to increase overall effectiveness, efficiency and productivity within the Terminal, by identifying and eliminating any bottlenecks within the system (all three areas), and revealing any resultant problems/opportunities of proposed solutions to these bottlenecks.

It should identify optimal queuing methodologies (number, size, location) and provide a model to test 'what if' scenarios in a simulated environment.

In addition, the study should provide a means to address the following points:

1. SHIP

a. Efficiency in crane allocation and crane performance.
b. Berth utilisation as a result of (1a).
c. Labour requirements as a result of (1a).

2. **LAND / TERMINAL**

a. Container storage arrangements needed to handle projected volumes.
b. Identify other limits on overall throughput.
c. Dwell times needed as a result of (2a).

3. **ROAD**

a. Optimum number of truck grids and time slots (Hours of Operation)
b. Expected truck turn-around-times.
c. Labour and machinery (straddle carrier) requirements as a result of (2a).

All of the above mentioned points need to be tested and compared against each other in regard to various estimated volumes and scenarios.

I anticipate that once the study has been successfully completed, P&O Ports will be able to continue to use and develop the model, with the possibility of enhancements for other terminal facilities.

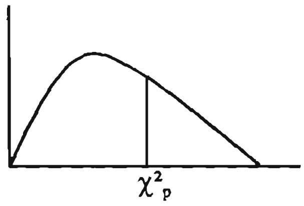
Please advise a suitable date for a final presentation (when known).

RON BEATTIE

Presentation Date: to be advised.

APPENDIX B

Table B.1. Percentile values (χ^2) for chi-square distribution, with ν degrees of freedom (area left of $\chi^2_p = p$).



ν	$\chi^2_{.995}$	$\chi^2_{.99}$	$\chi^2_{.975}$	$\chi^2_{.95}$	$\chi^2_{.90}$
1	7.88	6.93	5.02	3.84	2.71
2	10.60	9.21	7.38	5.99	4.61
3	12.84	11.34	9.35	7.81	6.25
4	14.96	13.28	11.14	9.49	7.78
5	16.7	15.1	12.8	11.1	9.2
6	18.5	16.8	14.4	12.6	10.6
7	20.3	18.5	16.0	14.1	12.0
8	22.0	20.1	17.5	15.5	13.4
9	23.6	21.7	19.0	16.9	14.7
10	25.2	23.2	20.5	18.3	16.0
11	26.8	24.7	21.9	19.7	17.3
12	28.3	26.2	23.3	21.0	18.5
13	29.8	27.7	24.7	22.4	19.8
14	31.3	29.1	26.1	23.7	21.1
15	32.8	30.6	27.5	25.0	22.3
16	34.3	32.0	28.8	26.3	23.5
17	35.7	33.4	30.2	27.6	24.8
18	37.2	34.8	31.5	28.9	26.0
19	38.6	36.2	32.9	30.1	27.2
20	40.0	37.6	34.2	31.4	28.4
21	41.4	38.9	35.5	32.7	29.6
22	42.8	40.3	36.8	33.9	30.8
23	44.2	41.6	38.1	35.2	32.0
24	45.6	43.0	39.4	36.4	33.2
25	49.6	44.3	40.6	37.7	34.4
26	48.3	45.6	41.9	38.9	35.6
27	49.6	47.0	43.2	40.1	36.7
28	51.0	48.3	44.5	41.3	37.9
29	52.3	49.6	45.7	42.6	39.1
30	53.7	50.9	47.0	43.8	40.3
40	66.8	63.7	59.3	55.8	51.8
50	79.5	76.2	71.4	67.5	63.2
60	92.0	88.4	83.3	79.1	74.4
70	104.2	100.4	95.0	90.5	85.5
80	116.3	112.4	106.6	101.9	96.6
90	128.3	124.1	118.1	113.1	107.6
100	140.2	135.8	129.6	124.3	118.5

Table B.2. Kolmogorov-Smirnov critical values.

Degrees of freedom N	$D_{0.10}$	$D_{0.05}$	$D_{0.01}$
1	0.950	0.975	0.995
2	0.776	0.842	0.929
3	0.642	0.708	0.828
4	0.546	0.624	0.733
5	0.510	0.565	0.669
6	0.470	0.521	0.618
7	0.438	0.486	0.577
8	0.411	0.457	0.543
9	0.388	0.432	0.514
10	0.368	0.410	0.490
11	0.352	0.391	0.468
12	0.314	0.375	0.450
13	0.304	0.361	0.433
14	0.295	0.349	0.418
15	0.286	0.338	0.404
16	0.278	0.328	0.392
17	0.272	0.318	0.381
18	0.264	0.309	0.371
19	0.24	0.301	0.363
20	0.22	0.294	0.356
25	0.24	0.27	0.32
30	0.22	0.24	0.29
35	0.21	0.23	0.27
Over 35	$1.22/\sqrt{N}$	$1.36/\sqrt{N}$	$1.63/\sqrt{N}$

APPENDIX C

ROAD VEHICLE OPERATION DATA ANALYSIS

C.1. Interarrival time of northbound trucks

A histogram of the experimental data of interarrival time of northbound trucks with each of the expected frequencies is shown in Figure C.1. A histogram is essentially a graphical estimate of the plot of the density function corresponding to the distribution of our data. Here the number of adjacent intervals in a histogram is the square root of the number of data points. The data summary and histogram summary are as follows:

Number of data points	= 155	Min data value	= 0.317
Max data value	= 10.3	Sample mean	= 1.47
Sample std dev	= 1.64	Histogram range	= 0 to 11
Number of intervals	= 12		

The plot in Figure C.1 is then matched with plots of densities of various distributions on the basis of shape alone to determine which distribution resembles the histogram. However, the 'Fit All' option of ARENA input analyzer is employed to perform a quick analysis and the distribution selected by the 'Fit All' option is based on minimising the square of the error. The square of the error is a measure of the quality of the distribution's match to the observed data. The lognormal distribution is selected after comparing the minimum square error value of various distributions. Table C.1 shows the lognormal distribution has the minimum square error value among all distributions for this set of data.

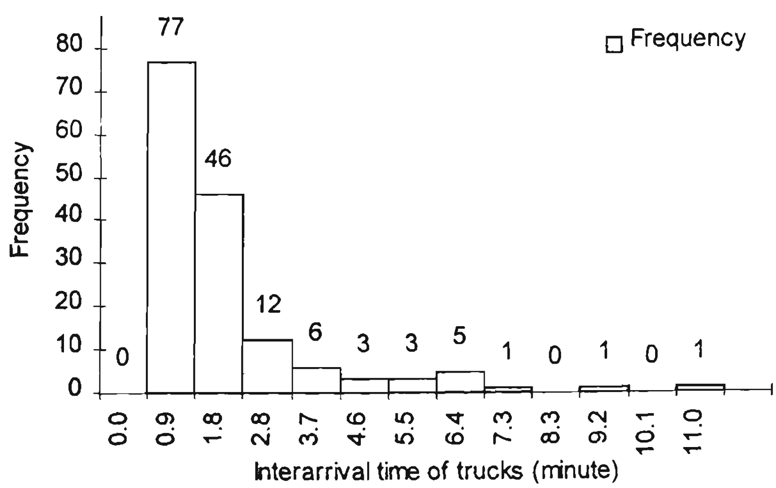


Figure C.1. Histogram of interarrival time for north bound trucks with an interval of 0.9 minute.

The match of the lognormal distribution with a mean 1.39 minutes and standard deviation 1.3 to the histogram representing interarrival time of northbound trucks is shown in Figure C.2.

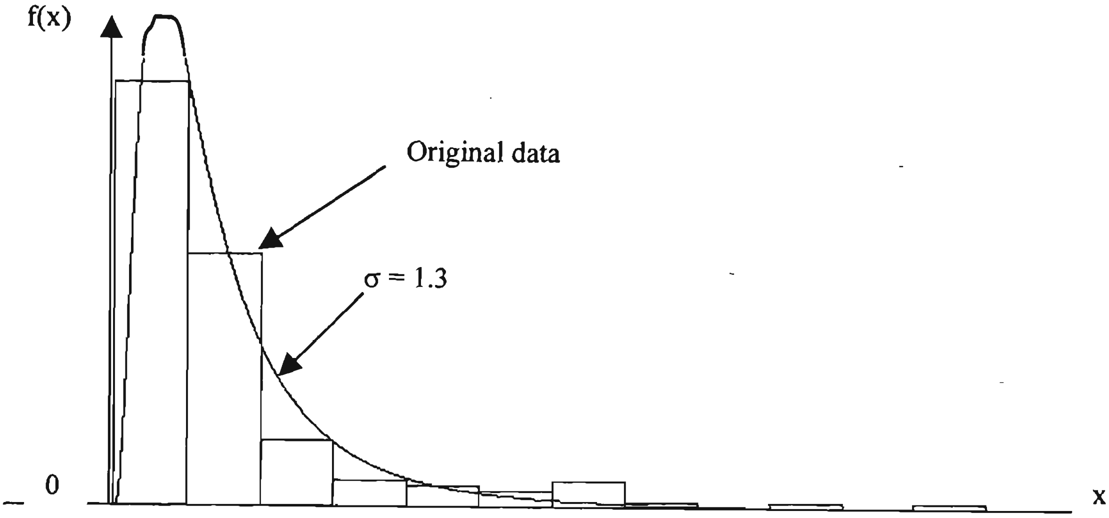


Figure C.2. Interarrival time of northbound trucks with lognormal distribution fit.

Table C.1. A comparison of square error value of various distributions shows the lognormal distribution has a smallest square error value.

Distribution function	***Sq. error***
Lognormal	0.00614
Exponential	0.00885
Erlang	0.00885
Weibull	0.0135
Gamma	0.0185
Beta	0.0187
Normal	0.129
Triangular	0.194
Uniform	0.261

The square error is calculated by taking the average of the square of the error terms for each histogram cell, which the square of the difference between the relative frequency of the observations in a histogram cell and the relative frequency for the fitted probability distribution function over the cell's data range. This analysis has been performed by the ARENA input analyzer. From this square error value, it can be seen that the larger the square error value, the further away the distribution is from the observed data. However, we cannot accept the lognormal distribution as fitting the observed data unless two standard statistical hypothesis tests (as described below) pass the match of distribution to the observed data. In our subsequent analysis, we have used these tests as a measure of the match of selected distribution to the data in comparison with other distributions.

There are two measures of a distribution's fit to the observed data: the Chi-Square and Kolmogorov-Smirnov (K-S) tests.

Testing the fit of distribution

Chi Square Test

Number of intervals	= 4	Degrees of freedom	= 1
Test statistic	= 5.38	Corresponding p-value	= 0.0217

The critical value of the test statistic (Chi-Square Statistic) from the Table B.1 of Appendix B (percentile values for the Chi-square distribution) at $\alpha_n = 0.05$ and ν (degrees of freedom) = 1 is 3.84. Since 5.38 > 3.84, we reject the null hypothesis (H_0) that there is difference between the observed and expected value from a lognormally distributed variable with a mean of 1.39 and a variance of 1.3. We also can see p-value is not large (< 0.05) indicating that the distribution is not a very good fit to the data.

K-S Test

Test statistic	= 0.122	Corresponding p-value	= 0.0194

The critical value for the K-S Statistic, with degrees of freedom $N = 155$ (sample size) and $\alpha_n = 0.05$ is $1.36/\sqrt{N} = 1.36/\sqrt{155} = 0.109$ (see Table B.2 of Appendix B critical values). Because 0.122 > 0.109, we reject the null hypothesis H_0 of difference between the observed and from a lognormally distributed variable. Again, we can see the p-value is not large indicating that the distribution is not a very good fit to the data.

Results from the above tests reveal that theoretical distribution did not match the observed data. Hence, we decided to use an empirical continuous distribution (see Figure C.3) to capture the characteristics of the observed data. Empirical distributions simply divide the actual data into groupings and calculate the proportion of values in each group. The continuous empirical distribution with an expression Continuous (0.00, 0.00, 0.497, 0.917, 0.794, 1.833, 0.871, 2.750, 0.903, 3.667, 0.929, 4.583, 0.948, 5.50, 0.981, 6.417, 0.987, 7.33, 0.987, 8.25, 0.994, 9.167, 0.994, 10.083, 1.0, 11.0) is shown in Figure C.3. The expression shows cumulative probabilities (e.g. between 0 and 1) and associated values (e.g. between 0 and 11.0 minutes).

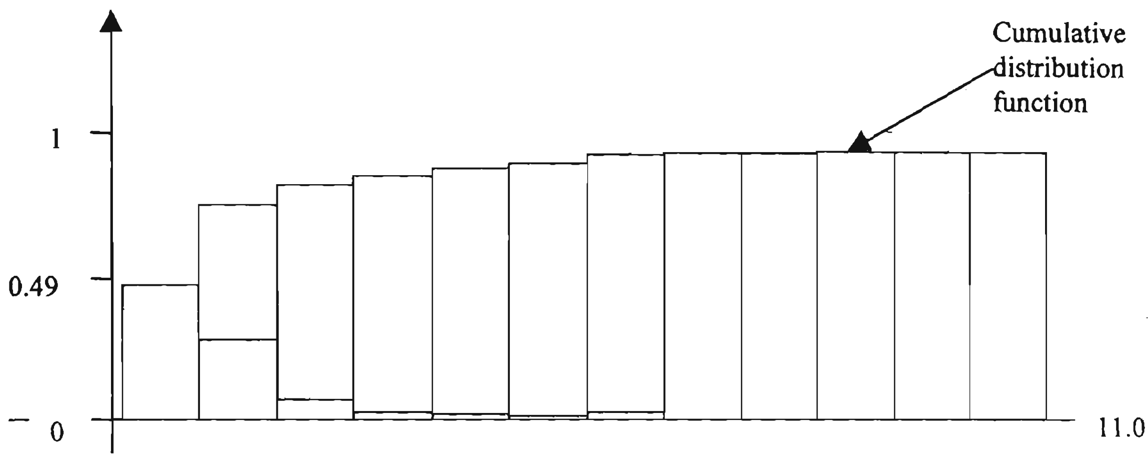


Figure C.3. Continuous empirical distribution for interarrival time of north bound trucks.

C.2. Interarrival time of south bound trucks

The experimental data are represented in the form of a histogram as shown in Figure C.4. The data and histogram summaries are as follows:

Number of data points = 120
Max data value = 13.6
Sample std dev = 2.3
Number of intervals = 10

Min data value = 0.167
Sample mean = 1.83
Histogram range = 0 to 14

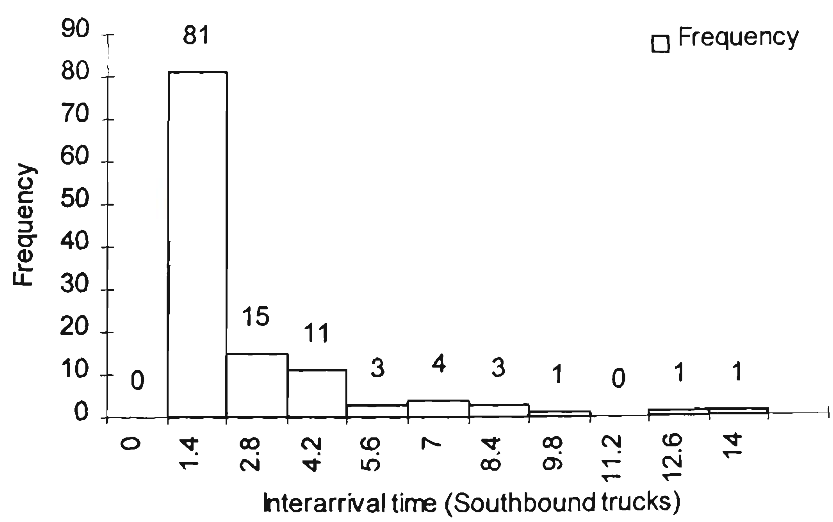


Figure C.4. Histogram of interarrival time for south bound trucks with a interval width of 1.4 minutes.

The fit of the distribution to the histogram is beta with a β (Scale parameter) equal to 0.42 and α (Shape parameter) 2.79 shifted to the right by 14 (e.g. 14 $\times$ Beta (0.42, 2.79)) shown in Figure C.5 based on the minimum square error value. Table C.2 shows the beta distribution has a minimum square error value of 0.00601 which is the lowest value of all those tested. However, this cannot be accepted unless the fit of distribution passes the standard statistical hypothesis tests.

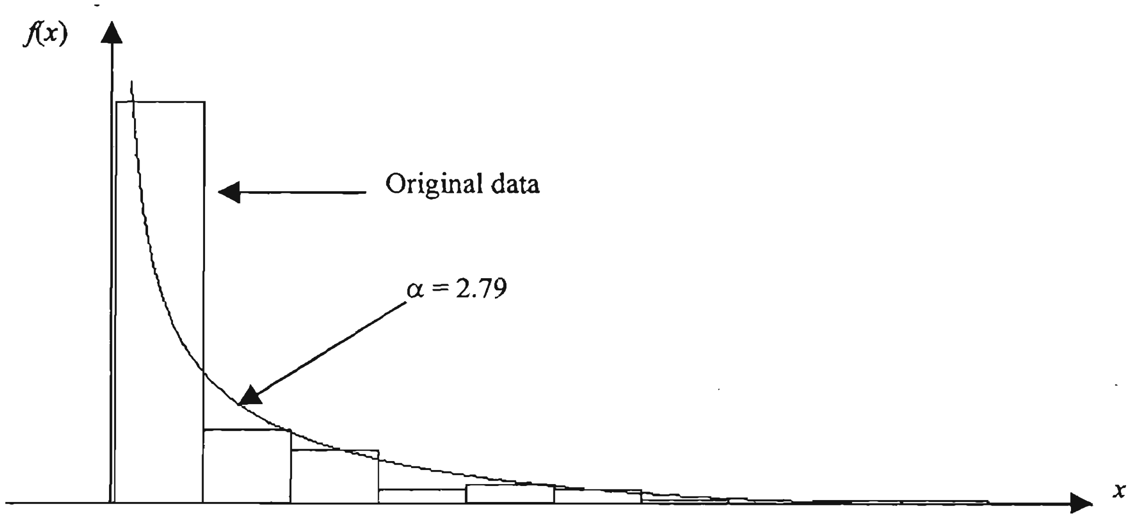


Figure C.5. Fit of beta distribution curve to interarrival time histogram.

Table C.2. A comparison of square error value of various distributions shows the beta distribution has a smallest square error value.

Distribution function	*Sq. error*
Beta	0.00601
Lognormal	0.0208
Weibull	0.0354
Exponential	0.037
Erlang	0.037
Gamma	0.0503
Normal	0.241
Triangular	0.317
Uniform	0.382

Testing the fit of distribution

Chi Square Test

Number of intervals =4
Test statistic =4.95

Degrees of freedom =1
Corresponding p-value = 0.0266

The critical value of the test statistic (Chi-Square statistic) from the Table B.1 (see Appendix B) at α_n = 0.05 and ν (degrees of freedom) = 1 is 3.84. Since 4.95 > 3.84, we reject the null hypothesis H_0 of significant difference between the observed and expected value from a beta distribution.

K-S Test

Test statistic = 0.312 Corresponding p-value< 0.01

The critical value for the K-S statistic, with degree of freedom N = 120 (observed data size) and α_n = 0.05 is $1.36/\sqrt{120}$ (see Table B.2 of Appendix B for critical values). Because 0.312 > 0.124, we reject the null hypothesis H_0 of difference between the observed and from a beta distribution function. We can see p-value is smaller. Both tests fail the matching of distribution to the data, so we decided to use an empirical continuous distribution to better capture the observed data. The continuous empirical distribution with an expression Continuous (0.00, 0.00, 0.675, 1.40, 0.80, 2.80, 0.892, 4.20, 0.917, 5.60, 0.95, 7.0, 0.975, 8.40, 0.983, 9.80, 0.983, 11.200, 0.992, 12.60, 1.00, 14.0) is shown in Figure C.5. The expression shows cumulative probabilities (e.g. between 0 and 1) and associated values (e.g. between 0 and 14.0 minutes)

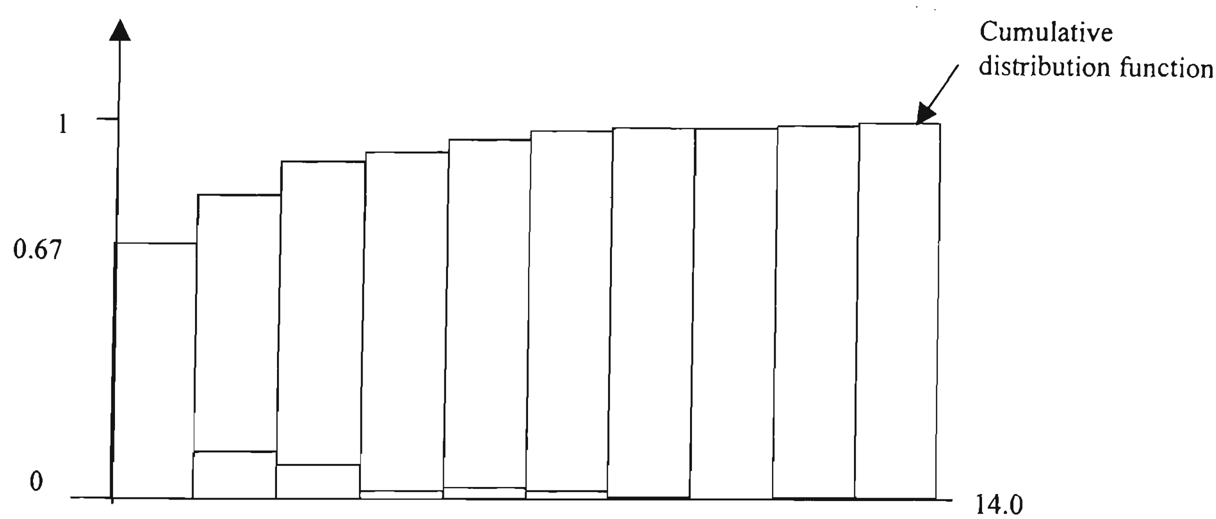


Figure C.5. Continuous empirical distribution for interarrival time of south bound trucks.

C.3. Time slot verification of trucks at entry gates D and E of the terminal

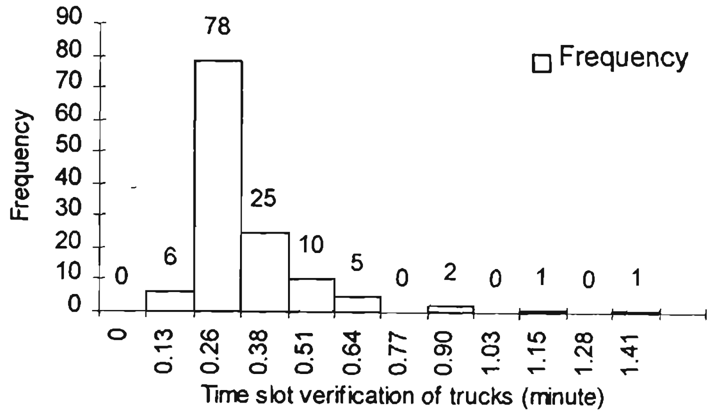


Figure C.7. Histogram of time slot verification at the entry gates of terminal.

Figure C.7 shows a histogram constructed from the base data as the time slot verification of trucks with a cell width of 0.13 minute. The data and histogram summary are given below.

Number of data points	= 128	Min data value	= 0.083
Max data value	= 1.28	Sample mean	= 0.274
Sample std dev	= 0.174	Histogram range	= 0 to 1.41
Number of intervals	= 11		

Figure C.8 shows the lognormal distribution curve which shows its density function drawn on the top of histogram with mean 0.269 and standard deviation parameter 0.133. The best selection of distribution is sorted, from best to worst, based upon the values of the respective square errors values in Table C.3 and shows the lognormal distribution has a minimum square error value.

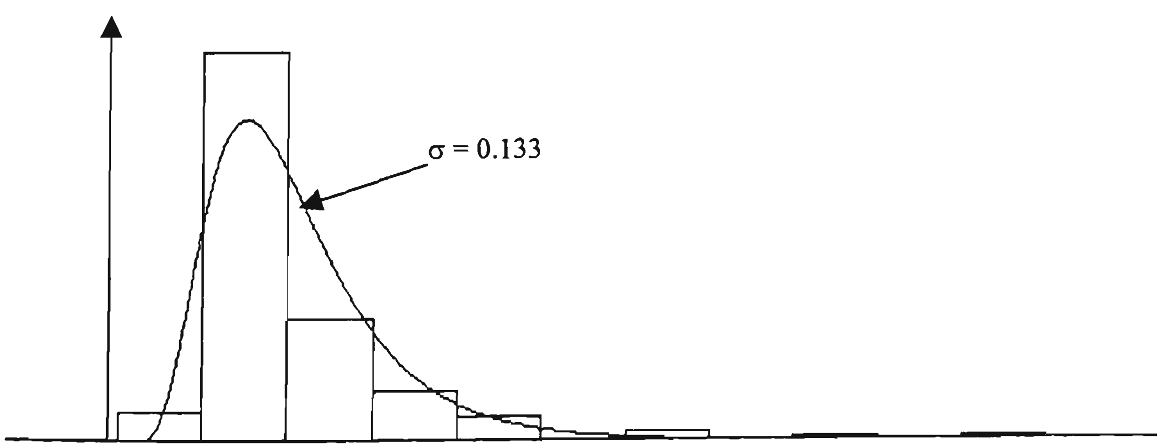


Figure C.8. Lognormal distribution fit to time slot verification of trucks data.

Table C.3. A comparison of square error value of various distributions shows the lognormal distribution has a smallest square error value.

Distribution function	*Sq. error*
Lognormal	0.0327
Erlang	0.0647
Gamma	0.0653
Beta	0.0932
Weibull	0.113
Normal	0.15
Triangular	0.234
Exponential	0.252
Uniform	0.329

Although the minimum square error value indicates the distribution is very close to the observed data it is required to pass standard hypothesis tests to accept a particular distribution.

Testing the fit of distribution

Chi Square Test

Number of intervals = 4
Test statistic = 13.2

Degrees of freedom = 1
Corresponding p-value < 0.005

The critical value of the test statistic (Chi-square statistic) from the Table B.1 of Appendix B (percentile values for the chi-square distribution) at $\alpha_n = 0.05$ and $\nu = 1$ is 3.84. Since $13.2 > 3.84$, we reject the null hypothesis H_0 that there is difference between observed and expected value from a lognormally distributed variable. It can also see the corresponding p-value is smaller than 0.05 indicates the data is not very good fit to distribution function.

K-S Test

Test statistic = 0.115

Corresponding p-value = 0.0638

The critical value for the K-S statistic, with degree of freedom $N = 128$ (sample size) and $\alpha_n = 0.05$ is 0.120 (e.g. $1.36/\sqrt{128}$). Because $0.115 < 0.120$, we do not reject the null hypothesis H_0 of no difference between what we observed and what we would expect to see from a lognormally distributed variable. The K-S test indicates that the lognormal distribution is best matched to the observed data despite the fact it fails the chi-square test. We accepted this distribution as we have a fair degree of confidence that we are getting a good representation of the data.

C.4. Paper-work gates of the terminal

There are five paper work gates for the documentation of trucks entering the terminal. The data were observed for each of five gates for documentation. The following sections are described for selection of distribution functions to our collected data.

C.4.1. Paper-work of trucks at Gate No. 1

The histogram of experimental data with frequencies is shown in Figure C.9. The data and histogram summary are given below.

Number of data points	= 112	Min data value	= 0.9
Max data value	= 11	Sample mean	= 3.58
Sample std dev	= 2.07	Histogram range	= 0 to 11
Number of intervals	= 10		

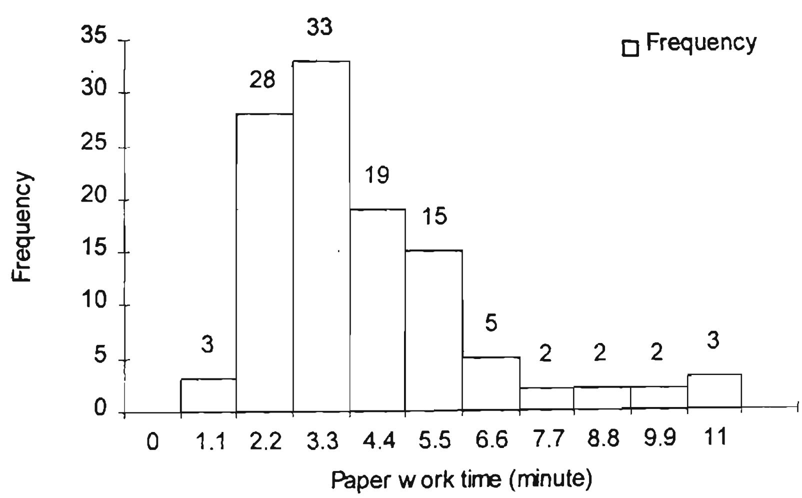


Figure C.9. Histogram of paper work at gate no. 1 with a cell width of 1.10 minute.

Figure C.10 shows the lognormal distribution match to the shape of the data with a mean of 3.57 and standard deviation 2 based upon the minimum square error value. From the Table C.4, it can be seen that lognormal distribution has minimum square error value in comparison with other distribution functions. This indicates that lognormal distribution is close to the observed data.

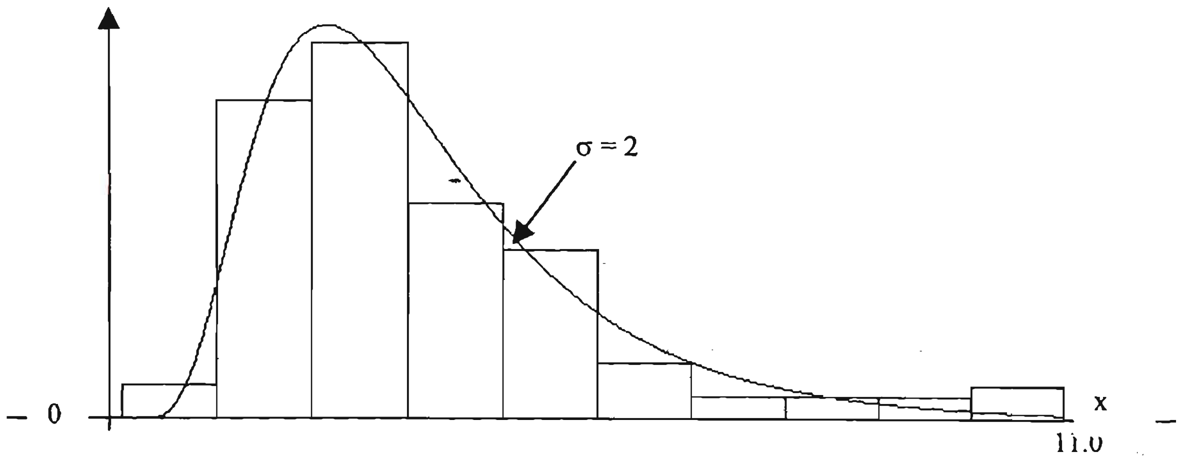


Figure C.10. Lognormal distribution fit for paper work at gate no. 1.

Table C.4. A comparison of square error value of various distributions for paper work at gate no. 1.

Distribution function	*Sq. error*
Lognormal	0.00286
Gamma	0.00728
Erlang	0.008
Weibull	0.0164
Beta	0.0243
Normal	0.0331
Triangular	0.0433
Exponential	0.0909
Uniform	0.1

Testing the fit of distribution

Chi Square Test:

Number of intervals = 5
Test statistic = 2.49

Degrees of freedom = 2
Corresponding p-value = 0.3

Critical value of test statistic (chi-square statistic) from the Table B.1 of appendix B at $\alpha_n = 0.05$ and $V = 2$ is 5.99. Since 2.49 < 5.99, we do not reject the null hypothesis H_0 of no significant difference between what we observed and what we would expect to observe from a lognormally distributed variable. The corresponding p-value is larger than 0.05 which indicates the distribution is a good fit to the data.

K-S Test

Test statistic = 0.0541 Corresponding p-value > 0.15

The critical value of the K-S statistic, with a degree of freedom N = 112 (data size) from the Table B.2 of appendix B and α_n = 0.05 is 0.128 (e.g. $1.36/\sqrt{112}$). Because 0.0541 < 0.128, we do not reject the null hypothesis H_0 of no difference between what we observed and what we would expect to see from a lognormally distributed variable. We can see that the p-value is larger than 0.05 which indicates a good fit. Both hypothesis tests indicate that the observed data is matched to the lognormal distribution.

C.4. 2. Paper-work of trucks at Gate No. 2

The data collected data on paper work gate no. 2 are shown in Figure C.11 with a cell width of one minute. The data and histogram summary are given below.

Number of data points	= 98	Min data value	= 0.75
Max data value	= 8.33	Sample mean	= 2.8
Sample std dev	= 1.66	Histogram range	= 0 to 9
Number of intervals	= 9		

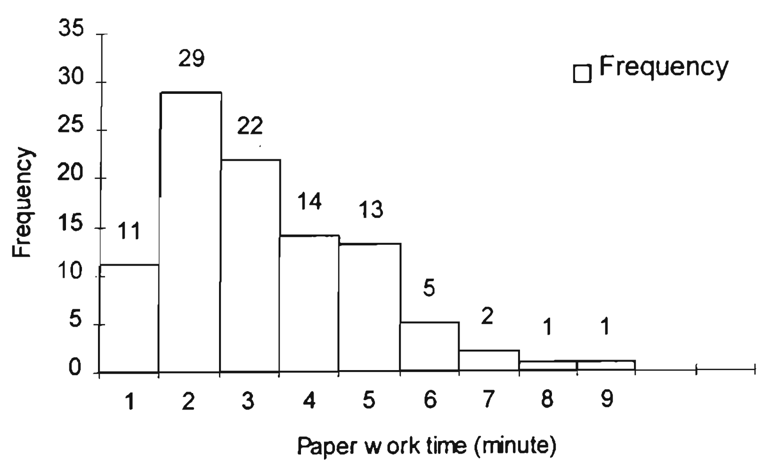


Figure C.11. Histogram of paper work time of trucks at gate no. 2.

Figure C.12 indicates that a gamma distribution with β = 0.941 and α = 2.97, provides the best fit in the sense of a minimum square error for the paper work time at gate no 2. Table C.5 shows the orders of the distribution from smallest to largest square error. We can see that gamma distribution has a low square error followed by Erlang, lognormal, and Weibull. This can be used as input to the model. The hypothesis tests can be used to assess whether a gamma distribution is a good fit to the data.

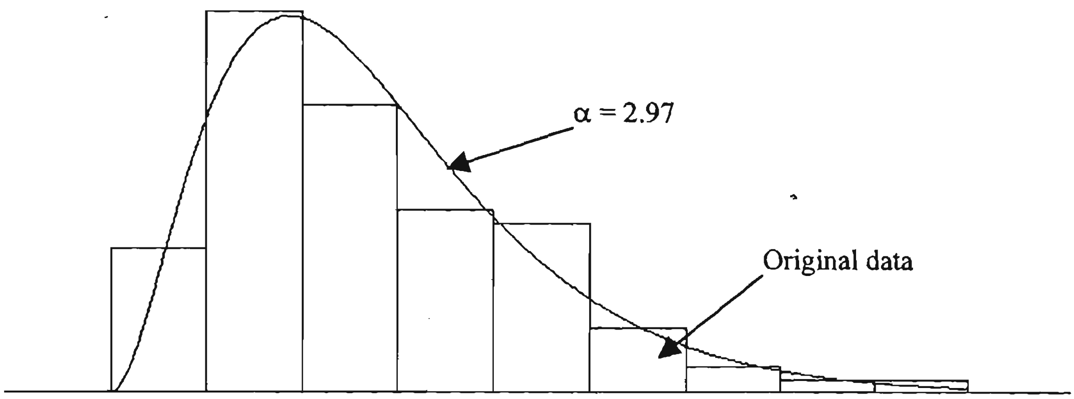


Figure C.12. Gamma distribution fit to the paper work time data at gate no 2.

Table C.5. A comparison of square error value of various distributions for paper work at gate no. 2.

Distribution function	*Sq. error*
Gamma	0.00461
Erlang	0.00468
Lognormal	0.0052
Weibull	0.00625
Beta	0.00747
Triangular	0.0189
Normal	0.0208
Exponential	0.0546
Uniform	0.0807

Testing the fit of distribution

Chi Square Test

Number of intervals = 4
Test statistic = 2.92

Degrees of freedom = 1
Corresponding p-value = 0.0904

The critical value of chi-square statistic from the Table B.1 of Appendix B at α_n = 0.05 and ν = 1 is 3.84. Since 2.92 < 3.84, we do not reject the null hypothesis H_0 of no significant difference between what we observed and what we would expect to observe from a beta distribution variable. The corresponding p-value indicates better fits.

K-S Test

Test statistic = 0.0773 Corresponding p-value > 0.15

The critical value for K-S statistic, with degree of freedom $N = 98$ (data size) and α_n = 0.05 is 0.137. Because 0.0773 < 0.137, we do not reject the H_0 of no difference between observed data and gamma distribution variable. The corresponding p-values are more than 0.05 which indicates that the distribution is a good fit. We therefore used the gamma distribution as input to the model.

C.4.3. Paper-work of trucks at Gate No. 3

Figure C.13 represents the histogram of the paper work time at gate no 3 with a cell width of 1.2 minutes. The data and histogram summary are described below.

Number of data points	= 117	Min data value	= 1
Max data value	= 13	Sample mean	= 3.08
Sample std dev	= 1.83	Histogram range	=1 to 13
Number of intervals	= 10		

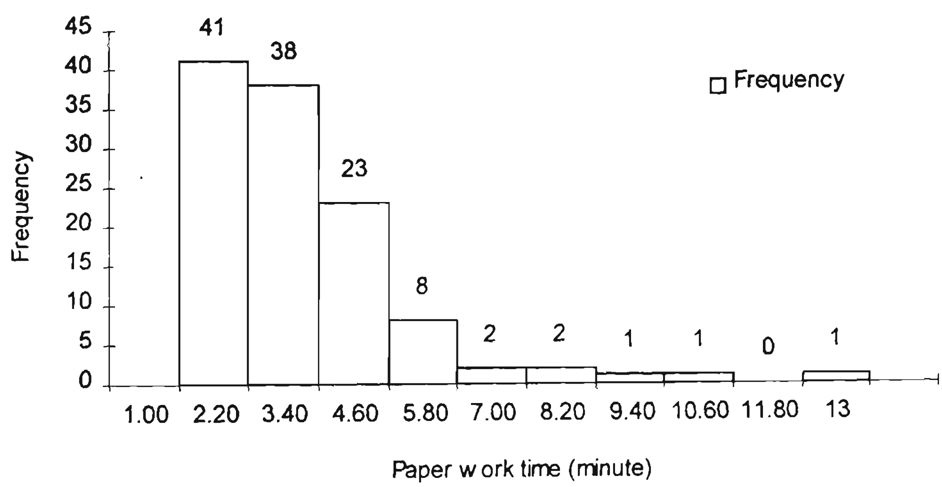


Figure C.13. Histogram of paper work of trucks at gate no. 3.

Figure C.14 shows that the gamma distribution with β = 1.47 (scale parameter) and α = 1.42 (shape parameter) shifted to the right by 0.999, provides the best fit on the basis of minimum square error. Table C.6 orders the distributions from the smallest to largest square error value. The same table shows the gamma distribution has a minimum of 0.0035 square error followed by Weibull, beta, and exponential distributions. The standard statistical hypothesis tests can be used to assess whether a fitted theoretical distribution is good fit to data.

Testing the fit of Gamma distribution curve:

Chi Square Test

Number of intervals = 4
Test statistic = 3.53

Degrees of freedom = 1
Corresponding p-value = 0.0639

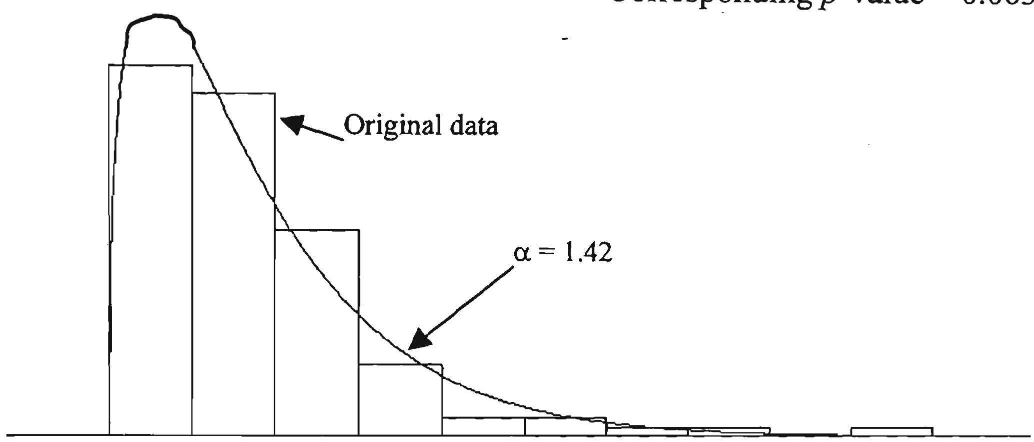


Figure C.14. Gamma distribution fit of paper work gate no. 3.

The critical value of test statistic from the Table B.1 of Appendix B at $\alpha_n = 0.05$ and $\nu = 1$ is 3.84. Since 3.53 < 3.84, we do not reject the null hypothesis H_0 of no significant difference between observed data and gamma distribution with the same parameter. The corresponding p-value is just above 0.05 which indicates a good fit.

K-S Test

Test statistic = 0.0733

Corresponding p-value > 0.15

The critical value for the K-S statistic, with a degree of freedom = 117 (data size) and $\alpha_n = 0.05$ is 0.1257. Because 0.0733 < 0.1257, we do not reject the null hypothesis H_0 of no significant difference between our observed data and what we would expect from a gamma distributed variable. The p-value is sufficiently high to accept the theoretical distribution input to the model.

Table C.6. A comparison of square error value of various distributions for paper work at gate no. 3.

Distribution function	*Sq. error*
Gamma	0.0035
Weibull	0.00365

Beta	0.0146
Exponential	0.0181
Erlang	0.0181
Lognormal	0.0234
Normal	0.0384
Triangular	0.0916
Uniform	0.172

C.4.4. Paper-work of trucks at Gate No. 4

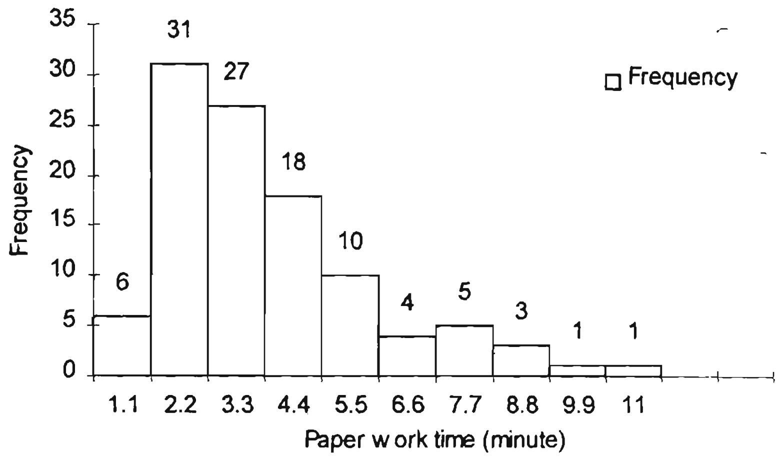


Figure C.15. Histogram of paper work of trucks at gate no. 4.

The histogram of measured data on the time to process paper-work of trucks at gate no 4 are shown in Figure C.15. The data and histogram summary are given below.

Number of data points	= 106	Min data value	= 0.005
Max data value	= 10.5	Sample mean	= 3.32
Sample std dev	= 2	Histogram range	= 0 to 11
Number of intervals	= 10		

The fitted distribution to histogram is shown in Figure C.16 indicates that a lognormal distribution with a mean 3.33 and standard deviation 2.12, provides the good fit in the sense of minimum square error. Table C.7 shows the square error of the various distributions and orders distributions from smallest to largest square error. The same table shows that the lognormal distribution has a minimum square error followed by Erlang, gamma, and Weibull distributions. The hypothesis tests are described in following sections.

$\sigma = 2.12$

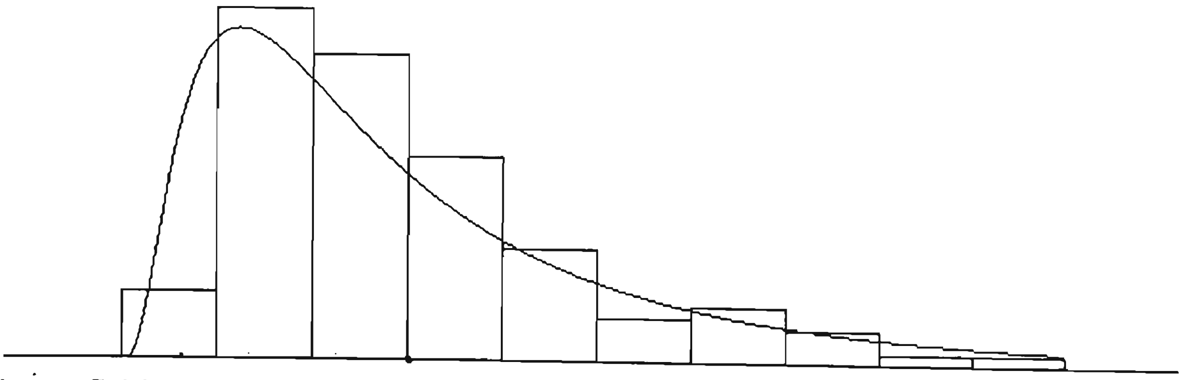


Figure C.16. Lognormal distribution curve with an expression Lognormal (3.33, 2.12).

Table C.7. A comparison of square error value of various distributions for paper work at gate no. 4.

Distribution function	***Sq. error***
Lognormal	0.0011
Erlang	0.00491
Gamma	0.00518
Weibull	0.0122
Beta	0.0163
Triangular	0.0278
Normal	0.0305
Exponential	0.0759
Uniform	0.096

Testing the fit of lognormal distribution curve

Chi Square Test

Number of intervals = 5
Test statistic = 0.626
Degrees of freedom = 2
Corresponding p-value = 0.0266

The critical value of the test statistic from the Table B.1 of Appendix B at $\alpha_n = 0.05$ and $\nu = 2$ is 5.99. Since 0.626 < 5.99, we do not reject the H_0 of no significant difference between our observed data and what we would expect from lognormal distribution variable. The p-value is less than about 0.05 which indicates that the distribution is not a very good fit.

K-S Test

Test statistic = 0.0485
Corresponding p-value > 0.15

The critical value for the K-S statistic, with degree of freedom 106 (data size) and α_n = 0.05 is 0.1320. Because 0.0485 < 0.1320, we do not reject the H_0 of no significant difference between observed data and lognormal distribution variable. The p-values indicate the distribution is a good fit.

C.4.5. Paper-work at Gate No. 5

Figure C.17 shows the histogram of the time to process the paper work of trucks at gate no 5. The data and histogram summary are described below.

Number of data points	= 75	Min data value	= 1.1
Max data value	= 13	Sample mean	= 3.31
Sample std dev	= 2.26	Histogram range	= 1 to 13
Number of intervals	= 8		

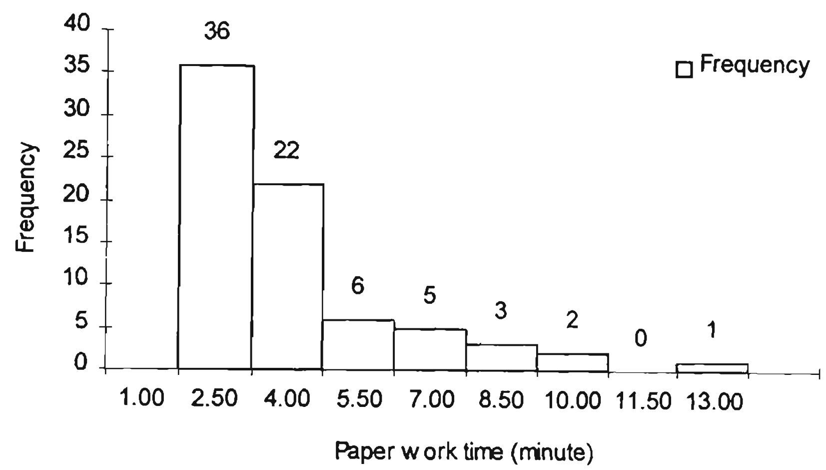


Figure C.17. Histogram of paper work of trucks at gate no. 5.

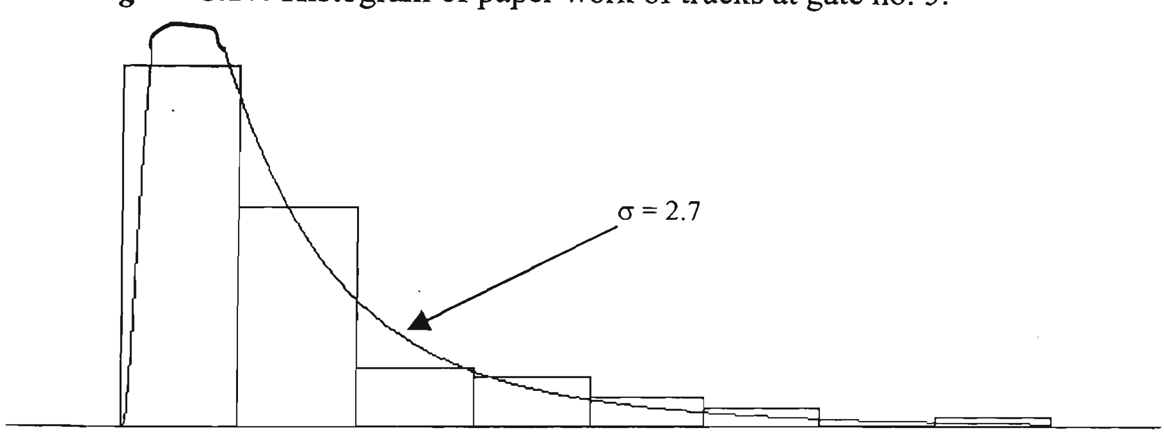


Figure C.18. Lognormal distribution fit of paper work time at gate no. 5.

Table C.8. A comparison of square error value of various distributions for paper work at gate no. 5.

Distribution function	*Sq. error*
Lognormal	0.00196
Erlang	0.0047
Exponential	0.0047
Weibull	0.00738
Gamma	0.00852
Beta	0.0115

Normal	0.096
Triangular	0.123
Uniform	0.205

Figure C.18 indicates that the lognormal distribution is a good fit in the sense that it has a minimum square error with a mean of 2.36 minute and standard deviation parameter 2.7 shifted to the right by 1. Table C.8 shows the lognormal distribution has a minimum square error followed by Erlang, exponential, and Weibull distributions.

Testing the fit of a lognormal distribution

Chi Square Test

Number of intervals = 4
Test statistic = 2.32
Degrees of freedom = 1
Corresponding p-value = 0.142

The critical value of the test statistic from the Table B.1 of Appendix B at $\alpha_n = 0.05$ and $\nu = 1$ is 3.84. Since 2.32 < 3.84, we do not reject the null hypothesis H_0 of no significant difference between our observed data and a lognormal distribution variable. The p-values also indicate that the distribution is a very good fit.

K-S Test

Test statistic = 0.0785
Corresponding p-value > 0.15

The critical value of the K-S statistic, with a degree of freedom $N = 75$ and $\alpha_n = 0.05$ is 0.1570. Because 0.0785 < 0.1570, we do not reject the null hypothesis H_0 of no significant difference between our observed data and a lognormally distributed variable. The p-value of more than about 0.05 indicates that the distribution is a good fit.

C.5. Processing time of trucks at the North Park grid

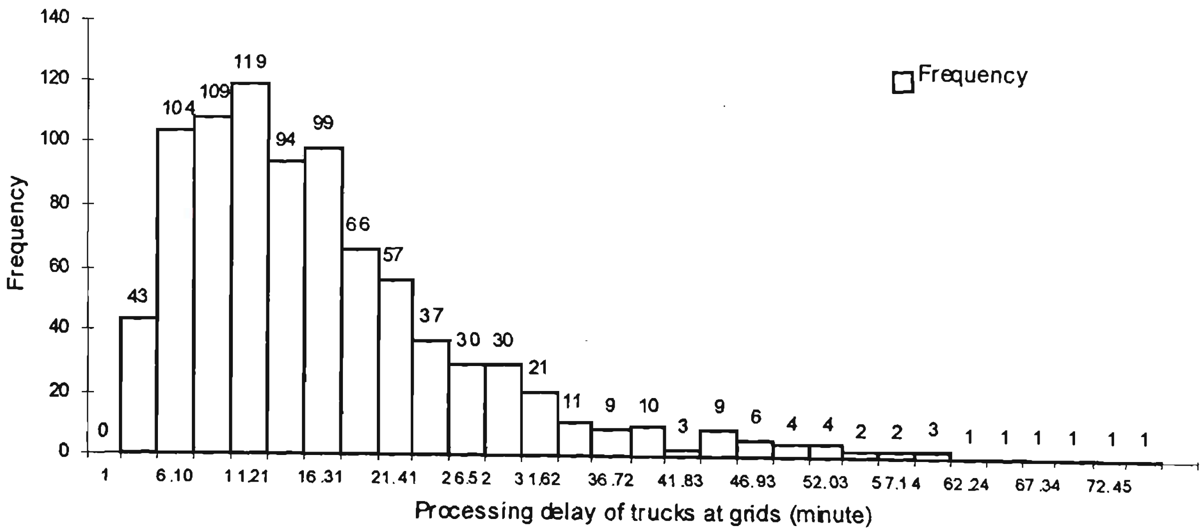


Figure C.19. Histogram of the processing delays of trucks at the North Park with a cell width of 2.55 minute.

The histogram of the experimental data on processing delays of trucks at North Park is shown in Figure C.19. The data and histogram summary are as follows:

Number of data points	= 878	Min data value	= 1.5
Max data Value	= 75	Sample mean	= 15.6
Sample std dev	= 11.2	Histogram range	= 1 to 75
Number of intervals	= 29		

Figure C.20 shows the results of the "Fit All" options for the processing delays at North Park and indicates that a gamma distribution with $\beta = 7.6$ (scale parameter) and $\alpha = 1.92$ (shape parameter), shifted to the right by 1, provides a good fit in the sense that the square error is a minimum.

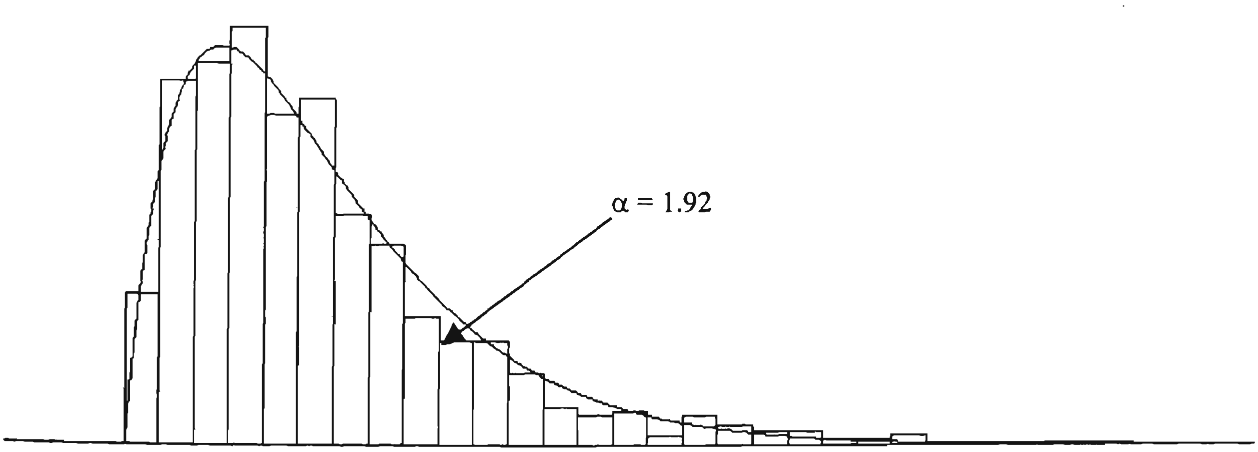


Figure C.20. Gamma distribution fit for processing time at North Park.

Table C.9. A comparison of square error value of various distributions for processing time at north park grids.

Distribution function	*Sq. error*
Gamma	0.000822
Erlang	0.00084
Weibull	0.0018
Lognormal	0.00268
Beta	0.00378
Normal	0.0139
Exponential	0.0183
Triangular	0.0329
Uniform	0.0551

Testing the fit of gamma distribution

Chi Square Test

Number of intervals = 17   Degrees of freedom = 14
Test statistic = 19.2   Corresponding p-value = 0.173

The critical value of test the statistic (chi-square statistic) from the Table B.1 of Appendix B at $\alpha_n = 0.05$ and ν (degree of freedom) = 14 is 23.7. Since 19.2 < 23.7, we do not reject the H_0 of no significant difference between our observed data and a gamma distributed variable. We can see that the p-value is more than about 0.05, which indicates the distribution is a good fit.

K-S Test

Test statistic = 0.0255   Corresponding p-value > 0.15

The critical value of the K-S statistic, with degrees of freedom $N = 878$ (observed data size) and $\alpha_n = 0.05$ is 0.0459. Because 0.0255 < 0.0459, we do not reject the H_0 of no significant difference between what we observed and what we would expect from a gamma distributed variable. The p-value is fairly high (e.g. 0.15), hence we can use a gamma distribution in the model.

C.6. Processing time of trucks at South Park grid:

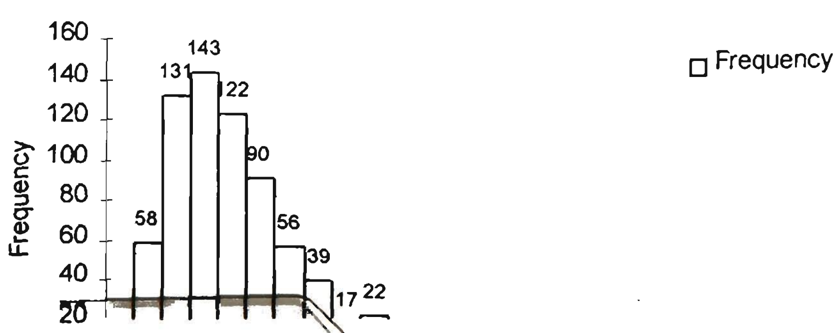


Figure C.21. Histogram of processing delays of trucks at South Park with a cell width of 4.38 minute.

Figure C.21 shows the histogram of processing times of trucks at South Park. The data characteristics are as follows:

Number of data points	= 707	Min data value	= 2.33
Max data value	= 116	Sample mean	= 18.6
Sample std dev	= 12.5	Histogram range	= 2 to 116
Number of intervals	= 26		

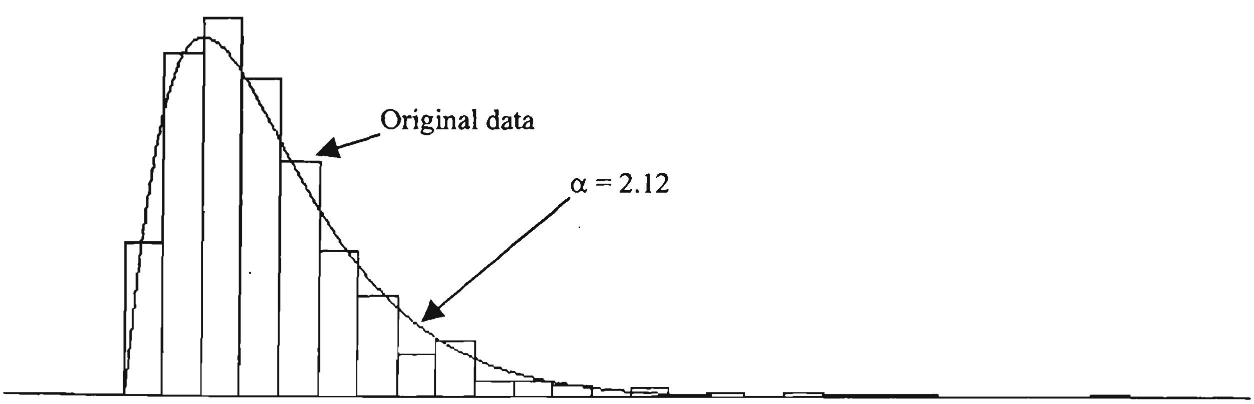


Figure C.22. Gamma distribution fit to processing time data at South Park of terminal.

Figure C.22 shows the results of the "Fit All" option of ARENA input analyzer for processing of trucks data at South Park and it indicates that a gamma distribution with parameters $\beta = 7.84$ and $\alpha = 2.12$, shifted to the right by 2, provides a good fit in the sense of having a minimum square error. Table C.10 is the square error summary for all distributions which shows the gamma distribution has a smallest error followed by the Erlang, lognormal, and beta distribution. The smaller this square error value, the closer the fitted distribution is to the data.

Table C.10. A comparison of square error value of various distributions for processing time at South Park grids.

Distribution function	*Sq. error*
Gamma	0.00107
Erlang	0.00151
Lognormal	0.00372
Beta	0.00417
Weibull	0.00514
Normal	0.0183
Exponential	0.0345
Triangular	0.0703
Uniform	0.101

Testing the fit of the gamma distribution

Chi Square Test

Number of intervals = 11 | Degrees of freedom = 8
Test statistic = 11.8 | Corresponding p-value = 0.175

The critical value of the test statistic (chi-square statistic) from the Table B.1 of Appendix B at $\alpha_n = 0.05$ and $\nu = 8$ is 15.5. Since $11.8 < 15.5$, we do not reject the null hypothesis H_0 of no difference between what we observed and what we would expect from a gamma distributed variable. Of particular interest is the p-value, which is fairly high (e.g. 0.175).

K-S Test

Test statistic = 0.0514 | Corresponding p-value = 0.0471

The critical value for the K-S statistic, with degrees of freedom $N = 707$ (data size) and $\alpha_n = 0.05$ is 0.05115. Because $0.0514 \cong 0.05115$, we do not reject the null hypothesis H_0 of no difference between what we observed and what we expect to see from a gamma distributed variable. We can see the p-value is little less than about 0.05. It is concluded that statistical tests might rank distributions differently. However, in our case the Chi-Square test indicates fairly high p-values, so we decided to use the gamma distribution.

APPENDIX D

DEVELOPMENT OF THE SIMULATION MODEL FOR ROAD VEHICLES OPERATIONS AT WEST SWANSON CONTAINER TERMINAL

D.1. Model Building Process

In our problem, trucks are arriving at the entry gates of the terminal are categorised as being north bound and south bound, and they either load or unload containers. The arrival of trucks at the two entry gates is different. In this module we have two distinct streams of arriving entities (assuming all entities in the system represent northbound and southbound trucks that are waiting for entry into the terminal) in our model, each with its different timing pattern. The ARENA block diagram for this system is depicted in Figure D.1.

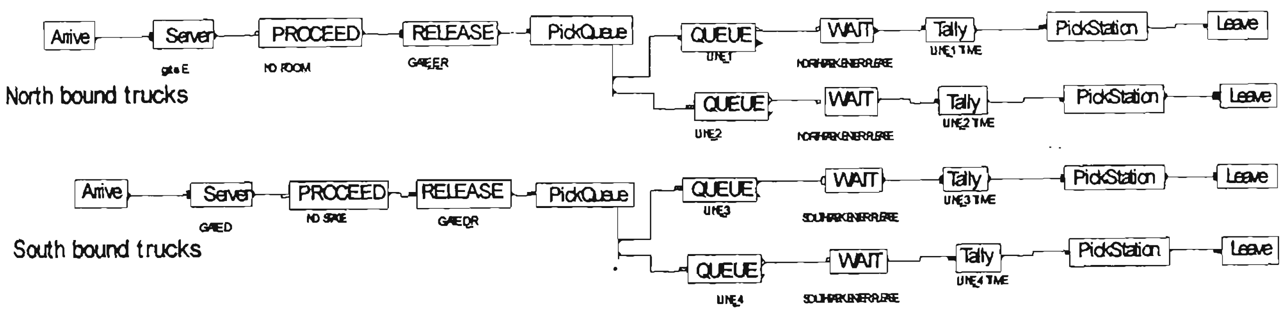


Figure D.1. Module listings for truck arrival, time slot verification, and waiting of trucks on lines.

Entities enter the model through *Arrive Modules*. An attribute TruckIn is set to the time in the *Arrive Module* that the northbound truck was created. Similarly, an attribute "TimeIn" is also marked in the *Arrive Module* for southbound trucks. Trucks for northbound enter the model at *Arrive Module* with an interarrival time sampled from an empirical continuous distribution with an expression of Continuous (0.0, 0.0, 0.480, 0.917, 0.791, 1.833, 0.872, 2.750, 0.905, 3.667, 0.932, 4.583, 0.946, 5.50, 0.980, 6.417, 0.986, 7.333, 0.986, 8.25, 0.993, 9.167, 0.993, 10.08, 1.00, 11.00). Similarly trucks for south bound enter the model at *Arrive Module* with an interarrival time sampled from an empirical continuous distribution with an expression of Continuous (0.0, 0.0, 0.675, 1.4, 0.80, 2.8, 0.892, 4.2, 0.917, 5.6, 0.95, 7.00, 0.975, 8.4, 0.983, 9.8, 0.983, 11.2, 0.992, 12.6, 1.00, 14.00). At the *Arrive*

Modules, assignments are made to the attributes TruckType as NORTH for northbound trucks and TruckType as SOUTH for southbound trucks.

Following the attribute assignments of *Arrive Modules*, the trucks proceed through a *Server Module* representing the time slot verification on gates D and E. The verification time is specified as a process times with distribution is Lognormal (0.269, 0.133).

After the time slot verification process, each truck continues to the *Proceed Module*. The *Proceed Module* tells the truck to continue only if the blockage is clear on Line1, Line2, Line3, and Line4 preceding the paper work gates (no. 1 to no. 5). The 6th truck coming in must wait on the Server (entry gate D and E), preceding that Line1, Line2, Line3, and Line4 until there is a space for it.

The Blockages Module is used in this model defining one blockage named NoRoom for the north bound trucks and an other blockage named NoSpace for southbound trucks with its initial number of blockages defaulted to 0. This module uses the QTIME rule for any ties that occur. In this value, the truck that has been in the queue the longest proceeds first.

After releasing the entry gate (i.e. D and E), the trucks enter *PickQueue Module* to select one of two queues Line_1 and Line_2, queues for north bound and Line_3 and Line_4 queues for south bound based on the Smallest number in Queue rule. If all the lines are at capacity, the truck will be wait on gates D and E.

In the *Queue Module*, the blockage level is defined as an expression. If the expression Block When (NQ(Line_1) >= 4) is true, the number of block points for the Blockage ID (NoRoom/NoSpace) is incremented by one and the queue is considered to be blocking. Otherwise, the queue is detached, meaning that trucks leave the queue via *Wait Module* once a signal is received. Statistics regarding queues has been defined in queue blocks separately in the model. The mark attributes LINE1IN, LINE2IN, LINE3IN, and LINE4IN are defined in the respective *Queue Modules* in order to measure the waiting time of trucks at different lines.

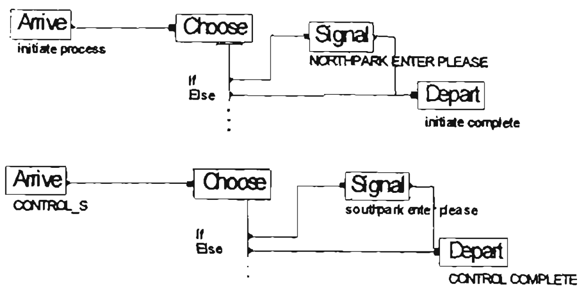


Figure D.2. External logic for entity removal (north and southbound trucks) from the wait modules.

The trucks in Line1, Line2, Line3, and Line4 wait for a signal from the external logic control before they are permitted to proceed to paper work gates. The model uses the external logic control (See Figure D.2) to create an entity using *Arrive* module every 0.00125 minutes to remove the trucks in the wait modules. Entities have no physical meaning and are normally referred to as logical entities. After this process, the entity enters the *Choose-Signal-Depart* sequence for evaluating the condition specified. If NR(gate1_r) + NR(gate2_r) + NR(gate3_r) + NR(gate4_r) + NR(gate5_r) .<=. 4.and .NE. (gate1) + NE(gate2) + NE(gate3) + NE(gate4) + NE(gate5) == 0, the entity is sent to *Signal Module* when signal code NORTHPARK ENTER PLEASE/ SOUTHPARK ENTER PLEASE sent to all the *Wait Modules* in the model. All trucks waiting for a code are released up to one truck at each time. At the end of this external logic control, the entity is disposed of at the *Depart Module*.

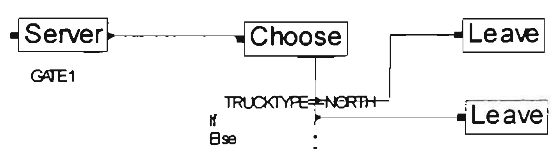
In the *Variable Module*, variables named NORTHPARK ENTER PLEASE and SOUTHPARK ENTER PLEASE are defined (see Figure D.8). There are no initial values specified, therefore, the initial values are 0. At *Wait Module* (see Figure D.1), when the signal is received, the trucks waiting in the preceding queue block are released up to one truck at a time. A check is made to see if North Park grid is busy or is less or equal to 11 and if queue at north park grid is less than 5 and there is no transfer of truck to grid, before releasing the trucks from the *Wait Module*.

Tally Modules are used in the model to record the interval of time between the previous event and the current simulated time for the trucks arriving at the *Tally Module*. This will measure the waiting time of trucks in respective queues.

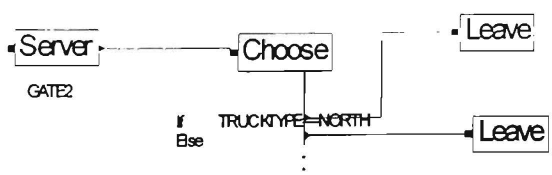
After the *Tally Module*, each truck continues to the *PickStation Module*. This module allows truck to select a particular station (say for example Gate1) from the multiple stations (i.e. Gate1, Gate2, Gate3, Gate4, and Gate5) specified. The selection of a gate among the group of gates is based on the selection logic defined with the module. Here the gate selection process is based on the minimum value of variables: the gate that has the least number of the sum of the trucks enroute to it and the number processing at the gate resource. The stations considered in the selection process are Gate1, Gate2, Gate3, Gate4 and Gate5. All the gate resources and number of trucks enroute to these are used in the evaluation. The selected gate is stored in the attribute gate choice. For Line1 trucks, station selection is defined in a sequence such as gate1, gate2, gate3, gate4, and gate5. For Line2, the sequence of gates is gate2, gate1, gate3, gate4, and gate5. For Line3 trucks, the sequence of gates is gate3, gate4, gate5, gate2, and gate1. Finally for Line4 trucks, the sequence of gates are gate4, gate5, gate3, gate2, and gate1.

After the selection of gates by trucks, at *PickStation Module*, all trucks are routed to their destinations via *Leave Module*. The time required to travel from gate E/gate D is a constant 0.50 minutes.

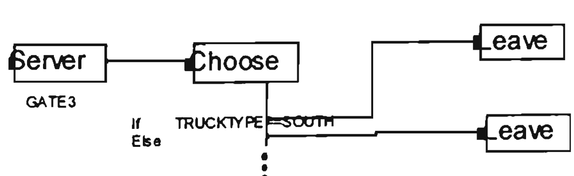
GATE NO. 1



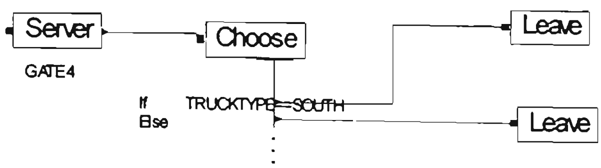
GATE NO. 2



GATE NO. 3



GATE NO. 4



GATE NO. 5

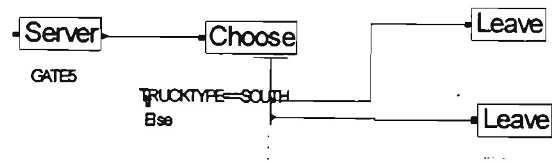


Figure D.3. Paper work processing at gate 1 to gate 5.

The trucks that enter gate1 for paper processing experience a delay sampled from a distribution Lognormal (3.57, 2). Similarly, the trucks entering different gates are then delayed for paper work by a time that is Gamma (0.941, 2.97) for gate2, 0.999 + Gamma (1.47, 1.42) for gate3, Lognormal (3.33, 2.12) for gate4, and 1 + Lognormal (2.36, 2.7) for gate5 (see Figure D.3).

After this, trucks leave or release the gates (servers) through *Choose Modules*. The arriving truck from the *Server Module* takes the first branch that is evaluated to true. If the attribute TruckType is North, the truck is sent to the North Park label, while all other trucks (TruckType == South) are sent to the label named South Park.

The trucks that are sent to the *Leave Module* labelled North Park or labelled South Park transfer to the next station NPG (North Park Grid) or SPG (South Park Grid) based on the condition evaluated at *Choose Module*. The time required to travel from any of gates 1 to 5 is uniformly distributed with a minimum of 1 unit of time to a maximum of 2 units of time for NPG (North Park Grid) station. However, for SPG (South Park Grid) station, the time required to travel from any of the five gates, is uniformly distributed with a minimum of 2 minutes to a maximum of 3 minutes.

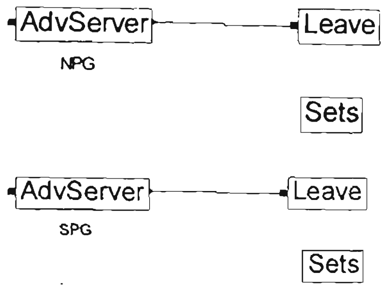


Figure D.4. Modules for North Park and South Park grid.

The Advanced Server Module is used to define enter, process and leave sequence of trucks in North Park/South Park Grid. Stations named NPG (North Park Grid) and SPG (South Park Grid) are defined in the enter process of *Advanced Server*. Trucks wait on the queues named NPQ and SP_Q to seize different resources named grid numbers (from grid number 7 to 18 for NPG and grid number 23 to 33 for SPG); the trucks enter the process data of *Advanced Server* where resource set NPG_S and SPG_S are defined for all resources. At *Sets Module*, one of 12 grid numbers is selected. The random rule (RAN) is specified to determine which member of the NPG_S or SPG_S is seized. The truck must seize a particular grid number. If there is no grid available, the truck will wait in queues NPQ and SP_Q of NPG and SPG respectively. The queue has a capacity of 5 and is not detached from the rest of the model. Before seizing any of 12 grids (no. 7 to 18) of NPG or any of 11 grids (no. 23 to 33) of SPG, the trucks enter the selection rule. It is used when a truck requires any one of 12 grid resources of NPG or 11 grids of SPG. At *Sets Module*, one of 12 grid numbers (11 grids of SPG) is selected (see figure D.5). The random rule (RAN) is specified for selection of grid. The truck must seize a particular grid number. If there is no grid available, the truck will wait in queue NPQ or SP_Q.

After passing through the selection rule, the trucks next enter for the processing sequence representing the processing delay of trucks on the grids. The trucks wait in the queue named NPQ, seize the resource named grids based on the random selection rule, delay for the time required to complete truck servicing, and then release the grids. The time it takes for servicing is 2 + Gamma (7.6, 1.92).

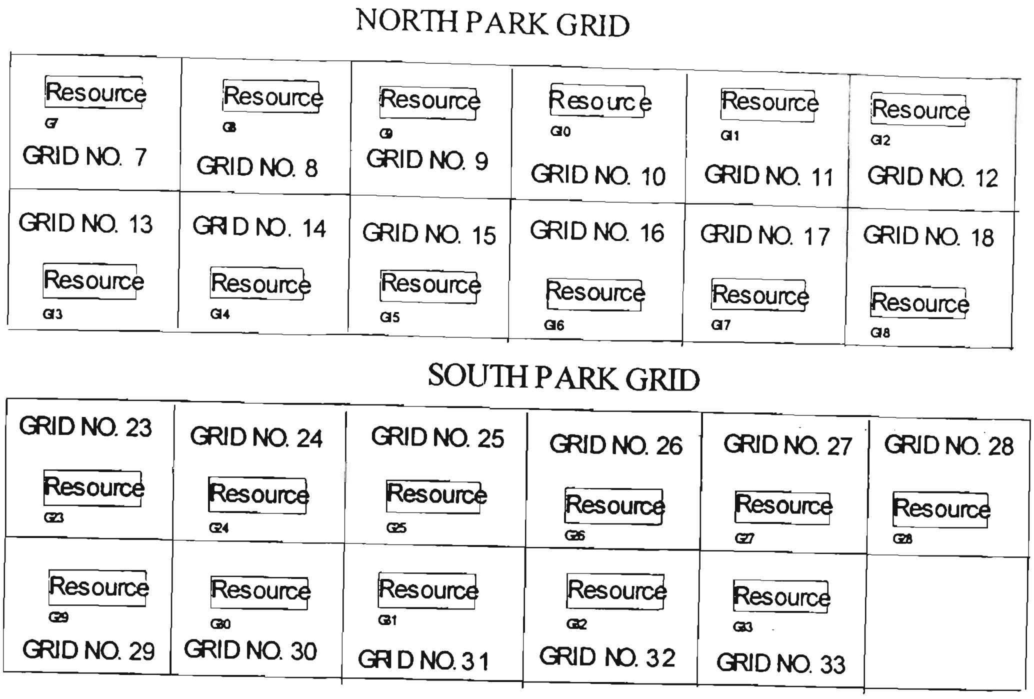


Figure D.5. Model listing for North Park and South Park Grid of terminal.

Several *Resource Modules* are used to define grid numbers of each park (see Figure D.5). However, these modules are needed to define characteristics of the resources (grid no. 7 to 18 and grid no. 23 to 33) that are not included in modules that reference it. The resources named G7 to G18 and G23 to G33 have a capacity of 1 for each with no allowance for shift breaks. Resources statistics are checked in each *Resource Module*. There are no queues specified in any of the resources labelled grid numbers.

At the completion of this sequence, the trucks enter a *Choose Module* where the arriving truck takes the first branch condition that is evaluated to true (see figure D.6). If NR(G7) + NR(G8) + NR(G9) + NR(G10) + NR(G11) +NR(G12) + NR(G13) + NR(G14) + NR(G15) + NR(G16) + NR(G17) +NR (G18) <= 11 .AND. NQ(NPQ) < 5 .AND. NE(NPG) == 0, the truck is sent to *Signal* Module when signal code NorthPark Enter Please sent to the entire *Wait Modules* in the model. If this condition fails, the truck is sent to the *Leave Module* for transfer to North Exit station labelled exit gate K. The time required to transfer is uniformly distributed with a minimum of 2 minutes of time and a maximum of 3 minutes of time.

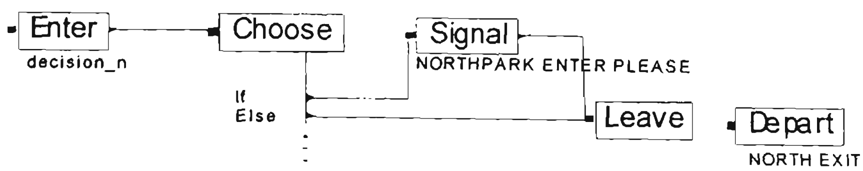


Figure D.6. Control logic for flow of trucks into North Park grid of terminal.

North Park grid sends a signal NorthPark Enter Please to the *Wait Module,* which receives this signal code (Figure D.6). The release of the truck at *Wait Module* depends on the system control. The system monitors the number of trucks in the queue at North Park grid (or South Park grid) as well as availability of grid positions. It sends a requisition for a truck to the North park grid or South park grid, if the north park grid (capacity =12 grids) is available and idle and the number in the queue at north park grid is less than 5. This ensures that North Park grid is never starved for trucks and that the queue at the North Park or South Park does not grow to extreme levels. A reason for monitoring this control could be limited waiting space in the terminal.

Similarly, for South Park grids, all modules used are the same as North Park grids except the delay times. The time it takes for servicing the trucks at grids by a time that is 1 + Gamma (7.6, 1.92). After completion of this sequence, the truck enters *Enter – Choose – Signal - Leave* sequence for evaluating the condition specified (see figure D.7). If NR(G23) + NR(G24) + NR(G25) + NR(G26) + NR(G27) + NR(G28) + NR(G29) + NR(G30) + NR(G31) + NR(G32) + NR(G33) <= 10 .AND. NQ(SP_Q) <5 .AND. NE(SPG) == 0, the truck is sent to *Signal Module* when signal code SouthPark Enter Please is sent to all the *Wait Modules* in the model. All trucks waiting for code SouthPark Enter Please are released up to one truck at each time at individual *Wait Modules*.

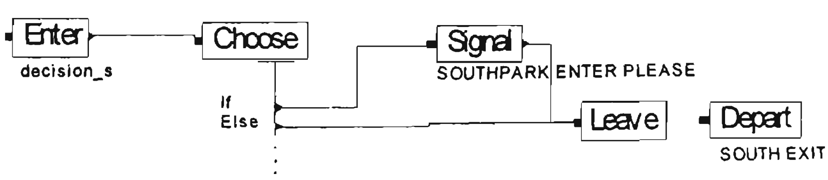


Figure D.7. Control logic for flow of trucks into South Park grid.

At the completion of this sequence, trucks transfer from North Park grid and South Park grid to exit gate K located at the south end of the container terminal. The time required to transfer is uniformly distributed with minimum of 1 minute of time and a maximum of 2 minutes of time.

At the end of this model, the *Depart Module* is used to remove (dispose) of trucks from the model (see Figures D.6 and D.7). The trucks arrive at the station named NORTH EXIT for North Park and SOUTH EXIT for south park. Counts and tallies are specified for each Depart Module labelled exit gate K. When a truck arrives at the station the counter North Truck is increased by 1. The time between the previous truck arrival and the current truck arrival is calculated and added to the tally turn-around time_N for northbound truck and turn-around time_S for southbound trucks.

The model defines the attributes, variables, queues, resources, and counters. In addition, the *Statistics Module* is included in the model to obtain time-persistent (DSTATS element) statistics on the availability of gates (gate 1 to gate 5), busyness of gates or whether gates are busy, and utilisation of gates (see Figure D.8). It provides similar statistics on the grids available (both north and south park grids), grids busy, and grids utilisation. Note that the rankings for all of the queues are defined as FirstIn FirstOut which means the trucks that entered the queue first will be the first to the exit the queue.

Simulate Module specifies the 30 replications of the simulation for 30 days (15 hrs × 60 units of time = 900 units of time for each replication) period.

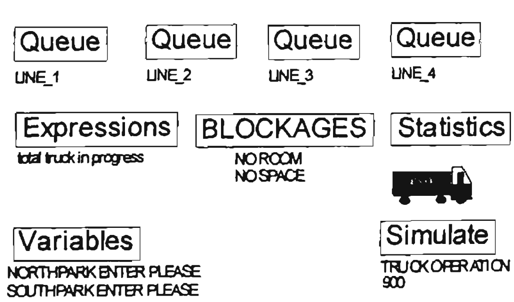


Figure D.8. Data modules for the model.

APPENDIX E

ANALYSIS OF EFFECTS FOR RESPONSE VARIABLES

E.1. Estimated effects for response: Truck turnaround time

The analysis has been carried out using S-Plus (S + Dox™ User's Manual, 1997) and the results are shown in Display E.1. The display shows the least squares estimate of each parameter, the standard error, the t statistic, and the corresponding p-value. The coefficients are determined by using the least square error method (see chapter 3). The least square estimator of ω is $\hat{\omega} = (X'X)^{-1}X'Y$ where X is the matrix of independent variables, X' is the transpose of a matrix X, Y is the vector of observations, and ω is the vector parameters to be estimated.

The variance-covariance matrix of the regression coefficients is estimated by $(X'X)^{-1}\hat{\sigma}^2$ where $\hat{\sigma}^2 = \frac{1}{n-1}\sum(y_i - \hat{y}_i)$ with $\hat{y}_i$ = fitted value of the ith observation and y_i is the observed value of the ith observation. The standard error (standard deviation) of each regression co-efficient is given by the square root of the corresponding element of the diagonal of the variance-covariance matrix. The t value is the ratio of the least square estimate of each parameter and its standard error. If the $|t|$ value exceeds the appropriate critical value of $t(l-u-1, 1-\alpha_n/2)$, then the hypothesis $H_0 : \omega_i = 0$ can be rejected.

R^2 is a measure of the amount of variability of y explained by the regression equation. R^2 is the ratio of sum of squares (SS) due to regression and sum of squares (SS) about the mean. The SS due to regression is the deviation of the predicted value of the ith observation from the mean [i.e. $\sum(\hat{y}_i - \bar{y})^2$]. The SS about the mean (total corrected) is the deviation of the ith observations from the overall mean [i.e. $\sum(y_i - \bar{y})^2$]. The proportion of total variability in turnaround time that is explained by this model is 0.9961. However, a large value of R^2 does not necessarily imply that the model is a good one.

The F test is the ratio of mean square due to regression and mean square due to residual variation. The ratio follows an F distribution with u (number of variables) and l-u-1 degrees of freedom under the hypothesis that all the regression coefficients are zero $H_0 : \omega_1 = \omega_2 = \cdots = \omega_g = 0$. The F-statistic here is 356.1, with a p-value of 2.902e-08. So the regression equation is significant since the F-statistic > F-critical (i.e. $F_{\alpha_n, u, l-u-1}$, the tabulated value of F). This indicates that at least one of the regression coefficients is non-zero. The residual plots indicated no serious lack of fit. To see if the regression equation is adequate the calculated F statistic was compared to the Box-Wetz criteria (see Draper and Smith, [1981, pp. 129-133]). For adequacy the calculated F needs to be at least that is 4 or 9 times the tabulated F value. For turnaround time the F value is 356.1 and clearly indicates the regression equation is adequate.

Display E.1. Summary of the scaled coefficients for truck turnaround time.

```
Call: lm(formula = tatime2 ~ x1 + x2 + x1sq + x2sq + x12)
Residuals:
     Min       1Q    Median      3Q     Max
 -0.4781 -0.1644 -0.09426 0.1228 0.9497

Coefficients:
                Value Std. Error  t value  Pr(>|t|)
(Intercept)  24.1750    0.2829    85.4655   0.0000
         x1   6.4140    0.2283    28.0938   0.0000
         x2  -4.5850    0.1774   -25.8414   0.0000
       x1sq   0.7273    0.3719     1.9556   0.0914
       x2sq   0.8416    0.3241     2.5968   0.0356
        x12  -0.4114    0.2535    -1.6233   0.1485

Residual standard error: 0.4733 on 7 degrees of freedom
Multiple R-Squared: 0.9961
F-statistic: 356.1 on 5 and 7 degrees of freedom, the p-value is
2.902e-08
```

E.2. Estimated effects for response: Total Trucks

Display E.2 gives the results of total truck analysis from the S-Plus statistical software package. The overall F-test, with a p-value of 9.152e-07, strongly suggests that at least one of the terms in our second-order model is important. The R^2 of 0.9895 indicates that our model explains almost 99% of the total variability, which is quite good. The test on the individual coefficients suggests that all of the terms are significant.

Display E.2. Summary of the scaled coefficients for total trucks (throughput daily).

```
Call: lm(formula = ttr2 ~ x1 + x2 + x1sq + x2sq + x12)
Residuals:
    Min      1Q Median     3Q    Max
 -20.24 -3.935 0.5746 3.905 11.14

Coefficients:
                 Value    Std. Error  t value     Pr(>|t|)
(Intercept)  1069.8058       6.3747   167.8214      0.0000
         x1    82.5700       5.1452    16.0479      0.0000
         x2    52.9147       3.9986    13.2332      0.0000
       x1sq   -83.9312       8.3812   -10.0142      0.0000
       x2sq   -20.9161       7.3036    -2.8638      0.0242
        x12    53.6793       5.7119     9.3978      0.0000

Residual standard error: 10.67 on 7 degrees of freedom
Multiple R-Squared: 0.9895
F-statistic: 131.7 on 5 and 7 degrees of freedom, the p-value is
9.152e-07
```

E.3. Estimated effects for response: North Park (NP) Utilisation

Display E.3 gives the results of NP Utilisation analysis from the S-Plus statistical software package. The R^2 is 0.9835 with a p-value 4.389e-06 which indicates that this model accounts for 98.35% of the variation about the mean in the data. The larger R^2 is, the better the fitted equation explains the variation in the data. The overall F-value associated with the complete second-order model is 83.46. The tabled 5% value of F for 7 and 5 degrees of freedom is 4.88. This indicates the fitted equation is sufficiently significant so that it is worthwhile to interpret the fitted surface.

Display E.3. Summary of the scaled coefficients for NP utilisation.

```
Call: lm(formula = nputi2 ~ x1 + x2 + x1sq + x2sq + x12)
Residuals:
    Min      1Q Median      3Q    Max
 -2.478 -1.299 0.1206 0.5206 3.886

Coefficients:
               Value   Std. Error t value  Pr(>|t|)
(Intercept)  68.6763    1.3160    52.1859   0.0000
         x1  12.4704    1.0622    11.7403   0.0000
         x2 -14.1607    0.8255   -17.1545   0.0000
       x1sq  -2.9601    1.7302    -1.7108   0.1309
       x2sq  -0.8336    1.5078    -0.5529   0.5975
        x12   1.4571    1.1792     1.2357   0.2564
```

```
Residual standard error: 2.202 on 7 degrees of freedom
Multiple R-Squared: 0.9835
F-statistic: 83.46 on 5 and 7 degrees of freedom, the p-value is
4.389e-06
```

E.4. Estimated effects for response: South Park (SP) utilisation

Display E.4 shows the results of estimates evaluated via least square methods from the S-Plus software. The overall *F*-test, with a *p*-value of 1.347e-08 indicates that the model is significant because it exceeds *F* (7, 5, 0.975) i.e. 7, and 5 are the degrees of freedom. The R^2 value indicates 99.69% of the variation of the data about the mean has been explained, which is quite good. The test on the individual coefficients suggests that all the terms except one term x_{u2}^2 are significant.

Display E.4. Summary of the scaled coefficients for SP utilisation.

```
Call: lm(formula = sputi2 ~ x1 + x2 + x1sq + x2sq + x12)
Residuals:
    Min       1Q Median     3Q    Max
 -0.995 -0.6136 0.1677 0.5784 0.965

Coefficients:
                  Value  Std. Error   t value  Pr(>|t|)
(Intercept)     56.1081     0.5419   103.5339    0.0000
         x1     -4.3411     0.4374    -9.9244    0.0000
         x2    -12.8332     0.3399   -37.7519    0.0000
       x1sq    -11.2721     0.7125   -15.8202    0.0000
       x2sq      0.2860     0.6209     0.4606    0.6591
        x12      2.5661     0.4856     5.2845    0.0011

Residual standard error: 0.9068 on 7 degrees of freedom
Multiple R-Squared: 0.9969
F-statistic: 443.9 on 5 and 7 degrees of freedom, the p-value is
1.347e-08
```

APPENDIX F

DATA ANALYSIS

F.1. Interarrival time of trucks on North Park grid

The data collected on the truck arrival pattern is shown in Figure F.1. The number of intervals is equal to the difference between the maximum (i.e. 71 minutes) and minimum data values (i.e. 2 minutes), plus one because the data are expressed in whole numbers.

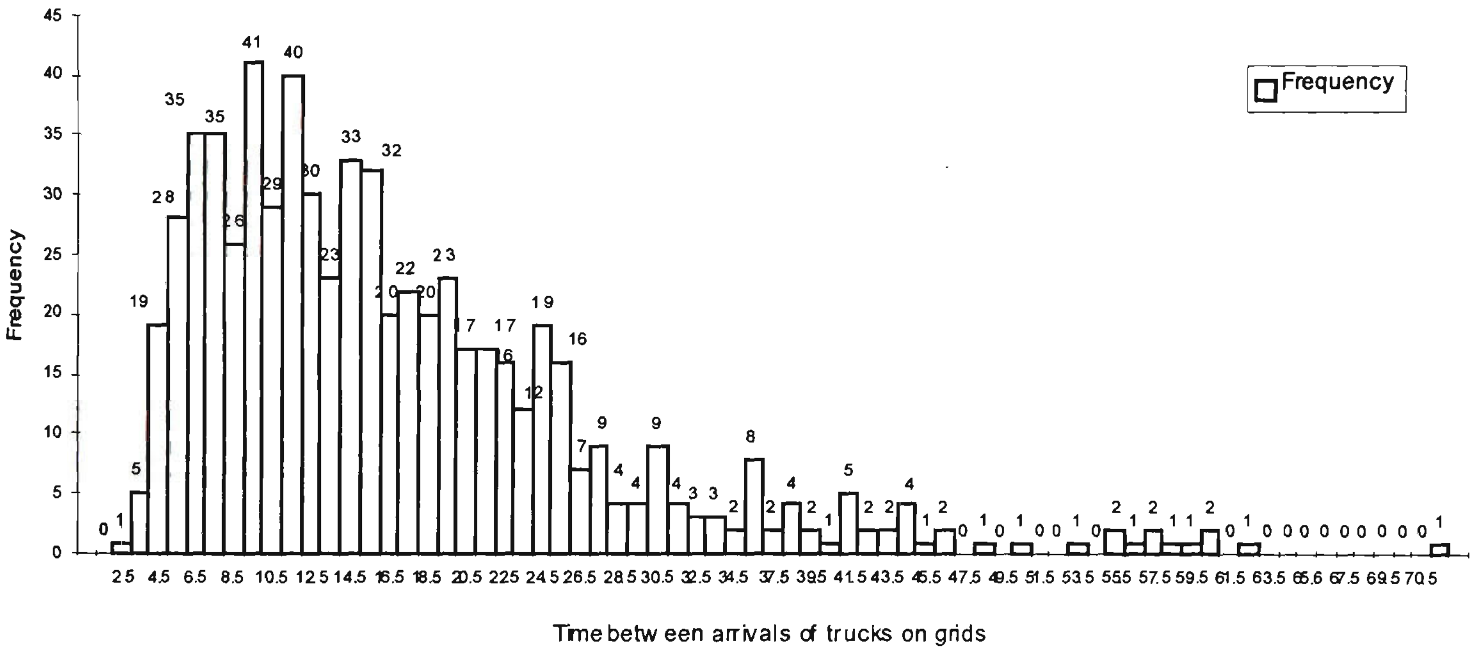


Figure F.1. Histogram of the interarrival-time data of trucks on North Park grid with a cell width of 1 minute.

Data and histogram summary for the interarrival-time:

Number of data points	=651	Minimum data value	= 2 minutes
Maximum data value	= 71 minutes	Sample mean	= 16.4 minutes
Sample std. dev.	= 10.8	Histogram range	= 1.5 to 71.5 minutes
Number of intervals	=70		

Fitting distribution to the data:

The gamma distribution with $\beta = 6.86$ (scale parameter) and $\alpha = 2.18$ (shape parameter) shifted to the right by 1.5 minutes has been fitted to the histogram as shown in Figure F.2, which shows its density function which is drawn on the top of the histogram. The selection of this distribution is sorted, from best to worst, based upon the values of the respective square errors. The square error value provided in the Table F.1 shows that gamma distribution has the minimum square error value. The selected distribution seems to adequately represent the data but we can not accept it unless we assess the quality of this fit. However, the results of the square error values are used as guidelines rather than precise scientific calculations, because the relative rankings can be affected by the number of intervals within the histogram or choice of histograms end points. One such goodness-of-fit test was attempted to measure and evaluate the deviation of the sample distribution from the theoretical. The corresponding *p*-value of Chi-Square test is the largest value of the type-1 error probability that allows the distribution to fit the data. The *p*-value (e.g. 0.076 > 0.05) indicates the plot in Figure F.2 that the gamma distribution [e.g. expression 1.5 + Gamma (6.86, 2.18)] is a good fit. We did not accept it until we checked the large *p*-value for other distribution functions. We performed data fitting to other functions, which has been described below.

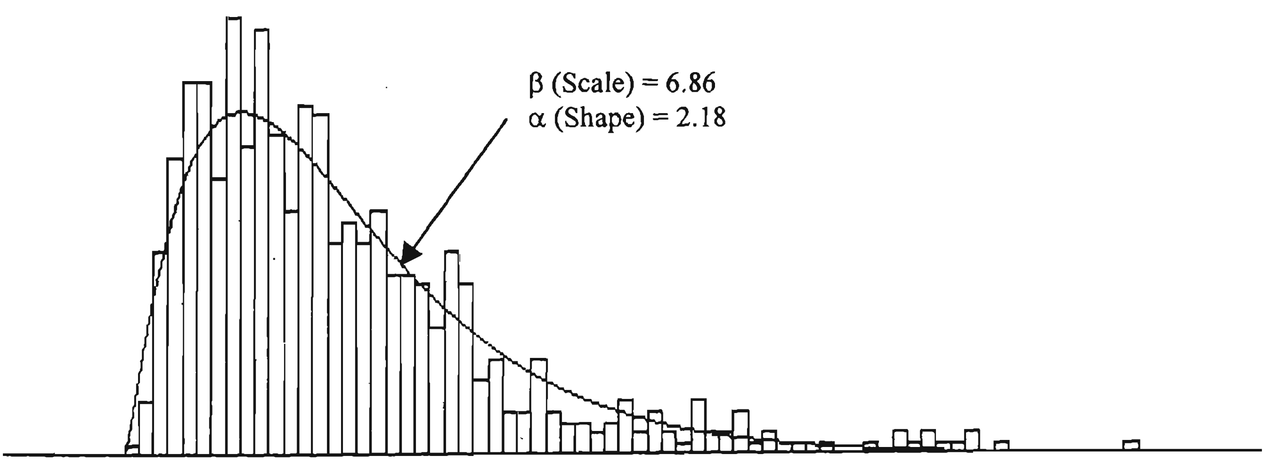


Figure F.2. Gamma distribution fit of truck arrivals at North Park grid.

Chi Square Test

Number of intervals	=31	Degree of freedom	= 28
Test statistic	=39.5	Corresponding *p*-value	= 0.0769

Figure F.3 shows lognormal distribution with a mean 15.2 and standard deviation 12.8, shifted to the right by 1.5 minutes, providing the best fit in the sense of high *p*-value (0.207). Therefore, we would not reject the null hypothesis of a good fit at this level. We can test alternatively by using critical value of the Chi-Square statistic from Table B.1 of

Appendix B at $\alpha_n = 0.05$ and ν (degrees of freedom) = 26 is 38.9. Since the calculated value of the Chi-Square statistic is 31.9 less than 38.9 we do not reject the null hypothesis H_0 that there is no difference between what we observed and expected value from a lognomal distribution. Comparing the plot with that in Figure F.2 indicates that this fitted lognormal distribution certainly appears to be a better representation of the data than the fitted gamma distribution.

Table F.1. Fitting of distribution to the data shows the smallest to largest square error value.

Distribution function	Square error value
Gamma	0.00157
Erlang	0.00164
Lognormal	0.00166
Weibull	0.00214
Beta	0.00242
Normal	0.00692
Exponential	0.0112
Triangular	0.0118
Uniform	0.023
Poisson	0.0328

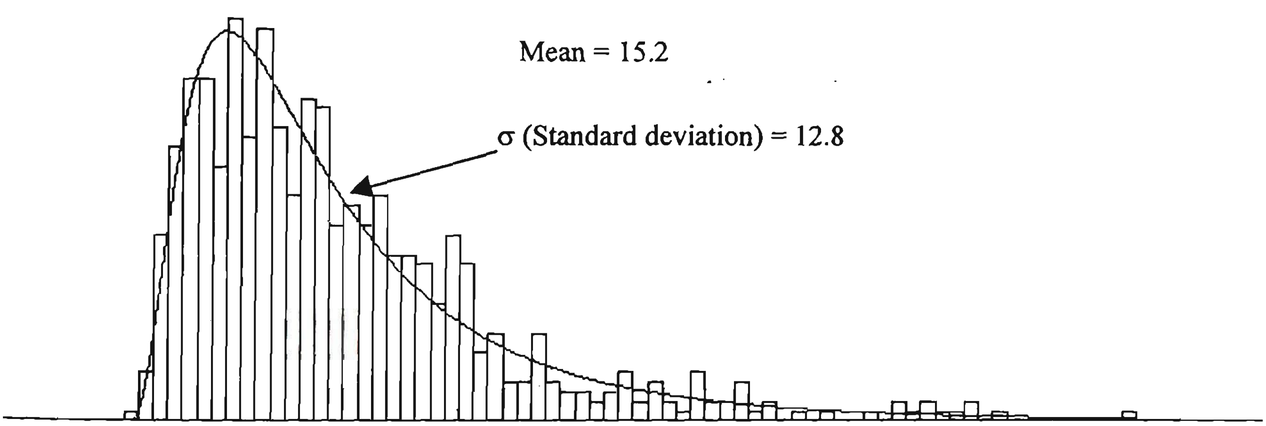


Figure F.3. Lognormal distribution fit to truck arrivals at North Park grid.

Chi Square Test:

Number of intervals	=29	Degrees of freedom	=26
Test Statistic	=31.9	Corresponding p-value	=0.207

F.2. Drop-off time of straddles at grids and yard areas

The data are represented by a histogram shown in Figure F.4. The number of intervals in the histogram is determined as the square root of the number of data points as the data points are real.

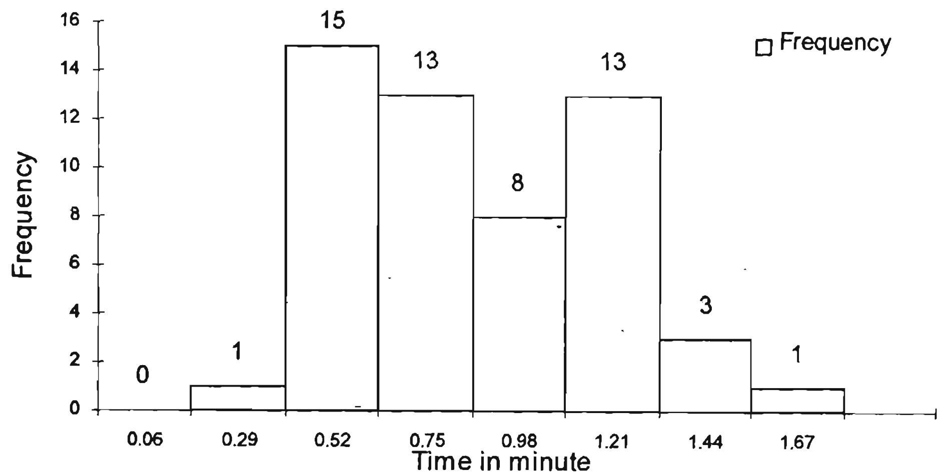


Figure F.4. Histogram of drop-off time with a cell width of 0.23 minutes.

Data and histogram summary:

Number of data points =54
Max data value =1.53 minutes
Sample std. dev. =0.306
Number of intervals =7

Min data value =0.2 minutes
sample mean =0.752 minutes
Histogram range =0.06 to 1.67

Fitting distribution to the data:

Figure F.5 indicates that the triangular distribution does fit our data particularly well with minimum of 0.06 minute, mode of 0.526, and maximum of 1.67 minute in the sense of minimum square error. Distributions from smallest to largest square error value are sorted in Table F.2. We can see in the same table that the triangular distribution has the minimum square error followed closely by beta, lognormal, gamma, and Weibull distributions.

Testing the fit of distribution:

Chi Square Test

Number of intervals =5
Test Statistic =5.19

Degrees of freedom =3
Corresponding p-value =0.175

The critical test statistic (Chi-Square statistic) from the Table B.1 of Appendix B with $\alpha_n = 0.05$ and $\nu = 3$ is 7.81. Since $5.19 < 7.81$, we do not reject the null hypothesis H_0 of no significant difference between what we observed and what we would expect to observe from a triangular distributed variable (see Figure F.5). The result of this test indicates a larger p-value.

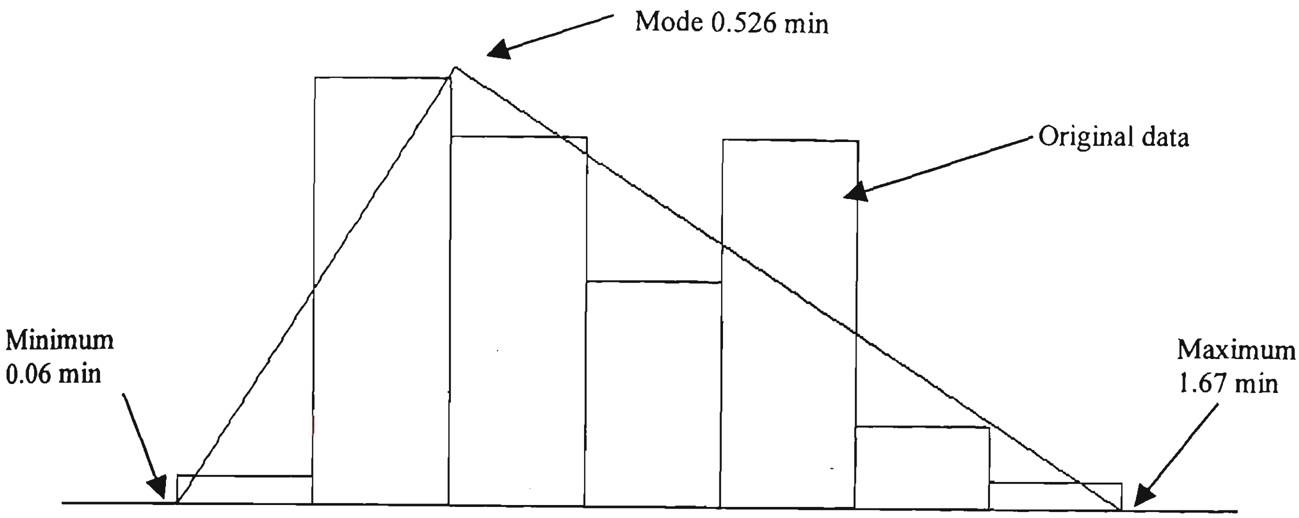


Figure F.5. Triangular distribution fit to loading time data of straddles.

Kolmogorov-Smirnov Test

Test statistic =0.0856 Corresponding p-value > 0.15

The critical value for the K-S statistic, with a degree of freedom $N = 54$ (data size) from the Table B.2 of Appendix B and $\alpha_n = 0.05$ is 0.1850 (e.g. $1.36/\sqrt{54}$). Because 0.0856 < 0.1850, we do not reject the null hypothesis H_0 of no difference between what we observed and what we would expect to see from a triangular distributed variable. Both tests indicate the triangular distribution is best matched to the observed data.

Table F.2. Fit all summary of distributions to the data shows the triangular distribution has a smallest square error value.

Distribution function	Square error value
Triangular	0.0207
Beta	0.0243
Lognormal	0.0262
Gamma	0.0278
Weibull	0.0305
Erlang	0.0308
Normal	0.0397
Uniform	0.0759
Exponential	0.114

F.3. Pick-up time of straddles at grids and yard areas

The data are represented by a histogram shown in Figure F.6. A summary of the data characteristics is given below together with histogram summary.

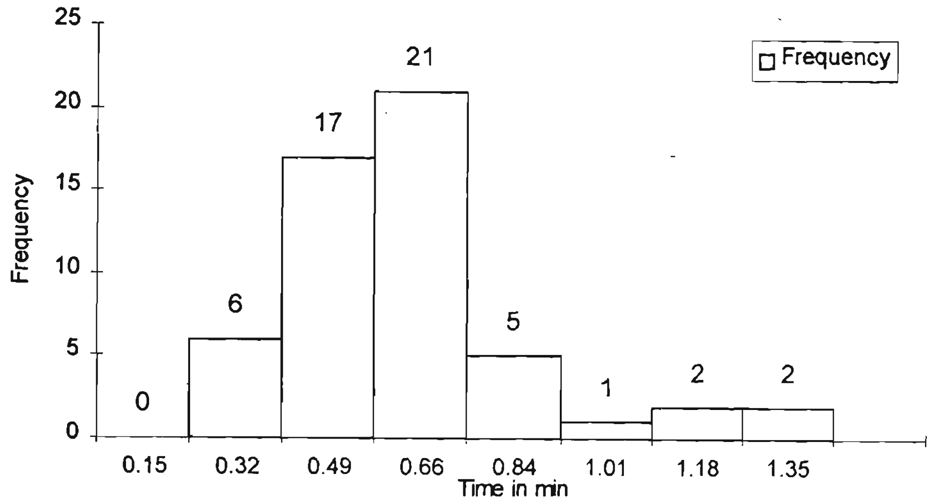


Figure F.6. Histogram for pick-up time with a cell width of 0.17 minutes.

Data and histogram summary

Number of data points =54
Max data value =1.25 minutes
Sample std. dev. =0.236
Number of intervals =7

Min data value =0.25 minutes
Sample mean =0.538 minutes
Histogram range =0.15 to 1.35

Fitting distribution to the data:

Figure F.7 indicates that fitted gamma distribution appears to be a better representation of the data. The gamma distribution with β (shape parameter) = 0.113 and α (scale parameter) = 3.42, shifted to the right by 0.15 minute, provides the best fit in the sense of minimum square error value (see Table F.3).

Testing the fit of distribution:

Chi Square Test

Number of intervals =4

Degrees of freedom =1

Test Statistic =4.05 Corresponding p-value =0.0457

The critical value of the test statistic (Chi-Square statistic) from Table B.1 of Appendix B at $\alpha_n = 0.05$ and $\nu = 1$ is 3.84. Since 4.05 > 3.84, we reject the null hypothesis H_0 of significant difference between what we observed and what we would expect to observe from a gamma distributed variable.

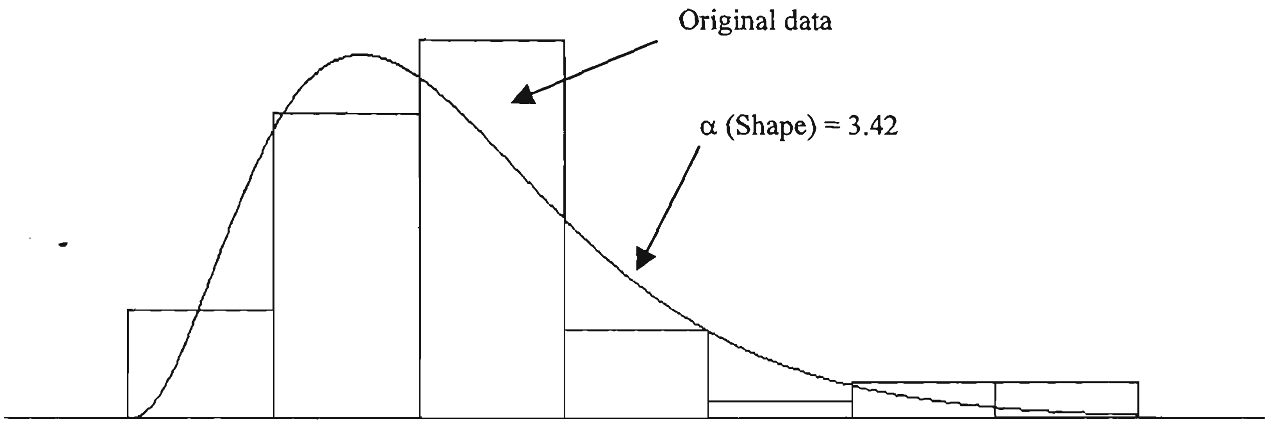


Figure F.7. Gamma distribution fit to pick-up time data of straddles.

Table F.3. Fit all summary of distributions to the data shows the gamma distribution has a smallest square error value.

Distribution function	Square error value
Gamma	0.0189
Erlang	0.023
Lognormal	0.027
Weibull	0.0273
Normal	0.0315
Beta	0.0343
Triangular	0.0791
Exponential	0.128
Uniform	0.131

Kolmogorov-Smirnov Test

Test Statistic =0.128 Corresponding p-value > 0.15

The critical value for the K-S statistic, with a degree of freedom N = 54 (data size) from table B.2 of Appendix B and $\alpha_n = 0.05$ is 0.1850 e.g., $\left(1.36/\sqrt{54}\right)$. Because 0.128 < 0.1850, we do not reject the null hypothesis H_0 of no difference between what we observed and what we would expect to see from a gamma distributed variable. However, only the K-S test measure indicates a good fit to the data and is used as input in our model.

F.4. Interfailure (break down) of straddles

The collected data on the breakdown of straddles have been summarized with a histogram shown in Figure F.8. The number of intervals is the square root of the data points (704) because the collected data is in real-value. The data and histogram summary are given below.

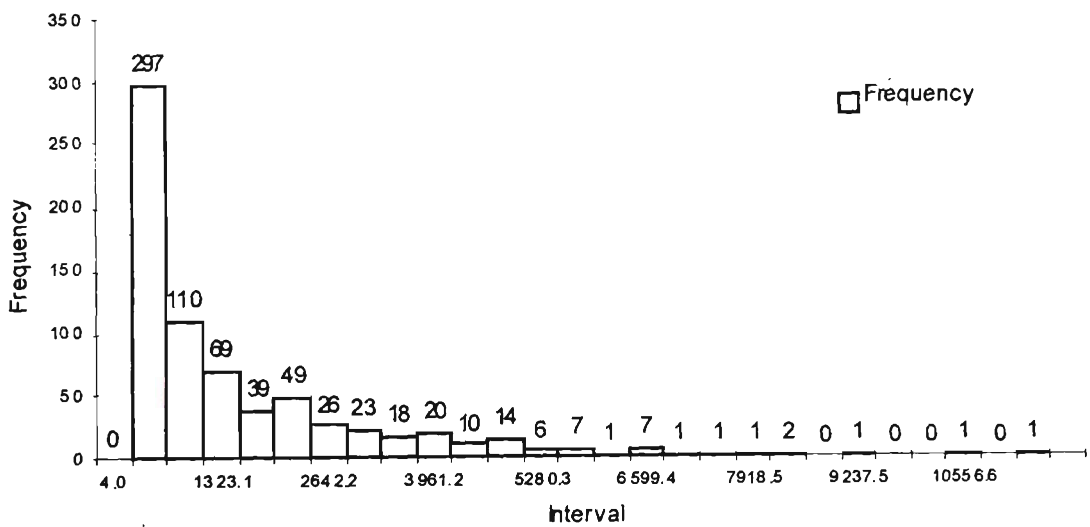


Figure F.8. Histogram of interfailure of straddles data with a cell width of 439.69 minutes.

Data and histogram summary

Number of data points =704
Max data value =11436 minutes
Sample std. dev. =1.61e+003
Number of intervals =26

Min data value =4.8 minutes
Sample mean =1272.241 minutes
Histogram range =4 to 11436

Fitting distribution to the data:

Figure F.9 indicates that the Weibull distribution with β (scale parameter) = 1.1e+003 and α (shape parameter) = 0.717 shifted to the right by 4.0, provides the best fit in the sense of minimum square error (see Table F.4).

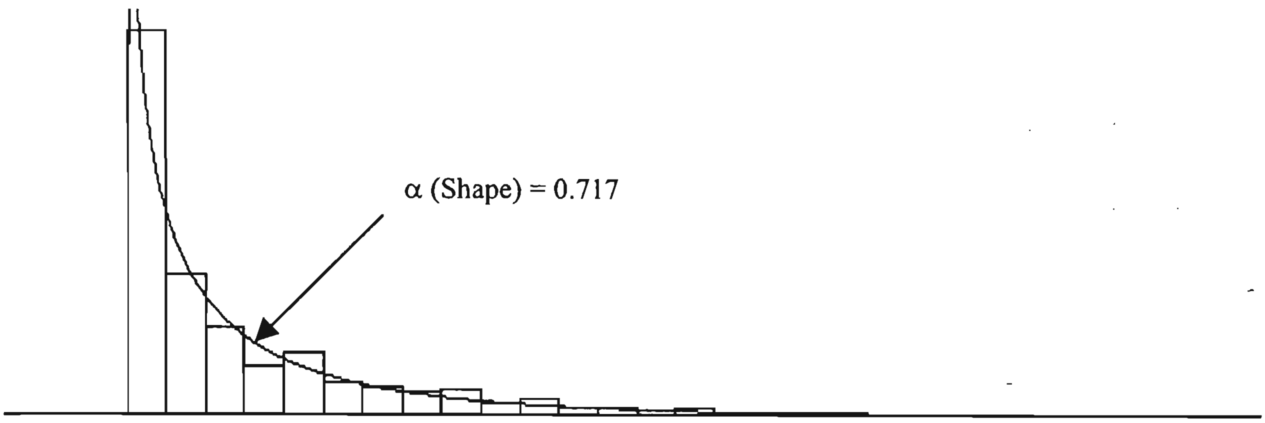


Figure F.9. Weibull distribution fit to break down time data of straddles.

Testing the fit of distribution:

Chi Square Test

Number of intervals	=13	Degrees of freedom	=10
Test Statistic	=21.4	Corresponding *p*-value	=0.0197

The critical value of the test statistic (Chi-Square statistic) from Table B.1 of Appendix B at α_n = 0.05 and ν (degree of freedom) = 10 is 18.3. Since 21.4 > 18.3, we reject the null hypothesis H_0 of significant difference between our observed data and a Weibull distributed variable. We can also use corresponding *p*-value from the results of this test for measure of goodness of fit to the data. Here p-value indicates a very low value of 0.0197 (e.g. < 0.05) and appears to be not a very good fit.

Kolmogorov-Smirnov Test

Test statistic =0.0378 Corresponding *p*-value > 0.15

The critical value of the K-S statistic, with degree of freedom (*N*) 704 (observed data size) and α_n = 0.05 is 0.051257 e.g. $\left(1.36/\sqrt{704}\right)$. Because 0.0378 < 0.051257, we do not reject the H_0 of no significant difference between what we observed and what we would expect from a Weibull distribution which is very close to the observed data. The

K-S test reveals that the data is a very good fit to the data and was used as input in the model. We can see corresponding p-value is also larger and indicates a good fit.

Table F.4. Fit all summary of distribution to the data shows the Weibull distribution has a smallest square error value.

Distribution function	Square error value
Weibull	0.00139
Beta	0.00158
Gamma	0.00428
Lognormal	0.00637
Exponential	0.0244
Erlang	0.0244
Normal	0.122
Triangular	0.153
Uniform	0.186

F.5. Repair time (short repair) of straddle carrier

The data on the straddle repair time of less than one hour has been summarized in the form of a histogram and show in Figure F.10. This data has not been considered in the model study.

Data and histogram summary

Number of data points	=165	Min data value	=0.2 minutes
Max data value	=60 minutes	Sample mean	=20.8 minutes
Sample std. dev.	=14.4	Histogram range	=0 to 60 minutes
Number of Intervals	=12		

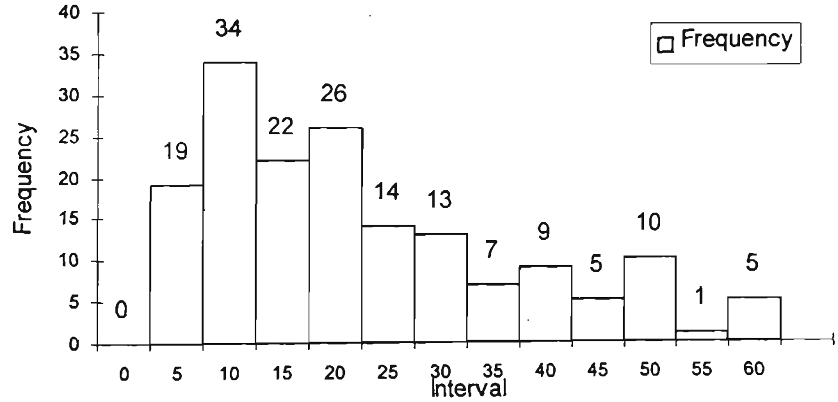


Figure F.10. Histogram of repair time less than one hour with a cell width of 5 minutes.

F.6. Repair time (planned maintenance) of straddle carriers

The data on the straddle repair time above one hour is shown in Figure F.11. This has not been included in the model study because of replacement of straddles.

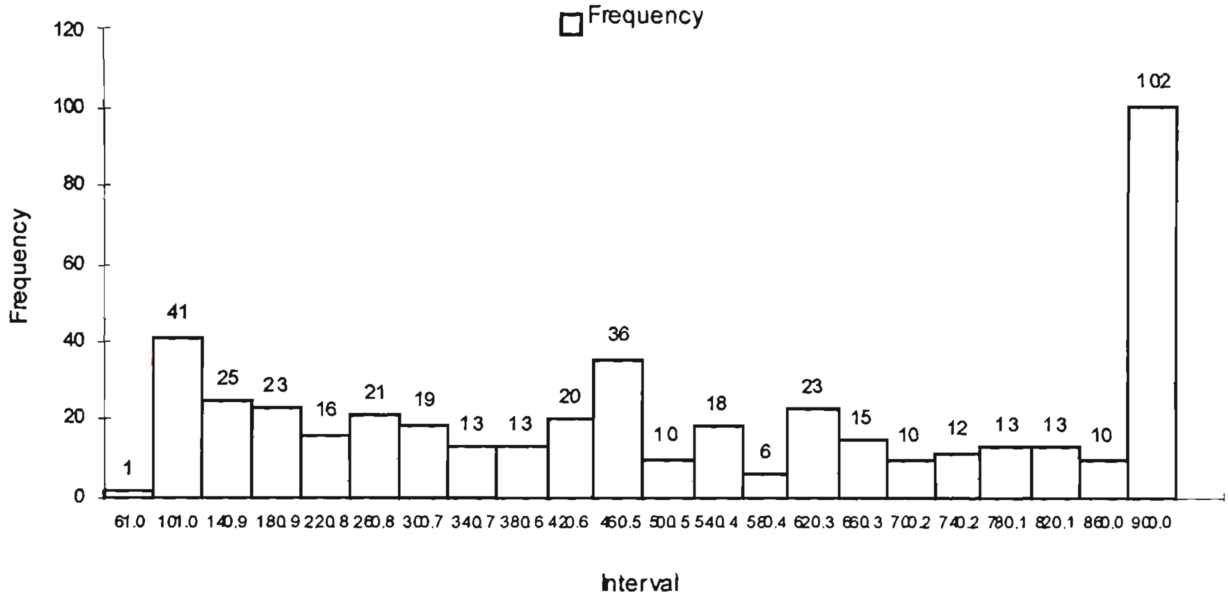


Figure F.11. Histogram of repair time above sixty minutes with a cell width of 39.95 minutes.

Data and histogram summary

Number of data points =460
Max data value =900 minutes
Sample std. dev. =292
Number of intervals =21

Min data value =61 minutes
Sample mean =508 minutes
Histogram range =61 to 900 minutes

F.7. Import container flow time in North Park

The data collected in import container flow time is shown in Figure F.12. This has been used for model validation process.

Data and histogram summary

Number of data points =1261
Max data value =15 minutes
Sample std deviation =2.33
Number of Intervals =15

Min data value =1 minute
Sample mean =5.35 minutes
Histogram range =0.5 to 15.5

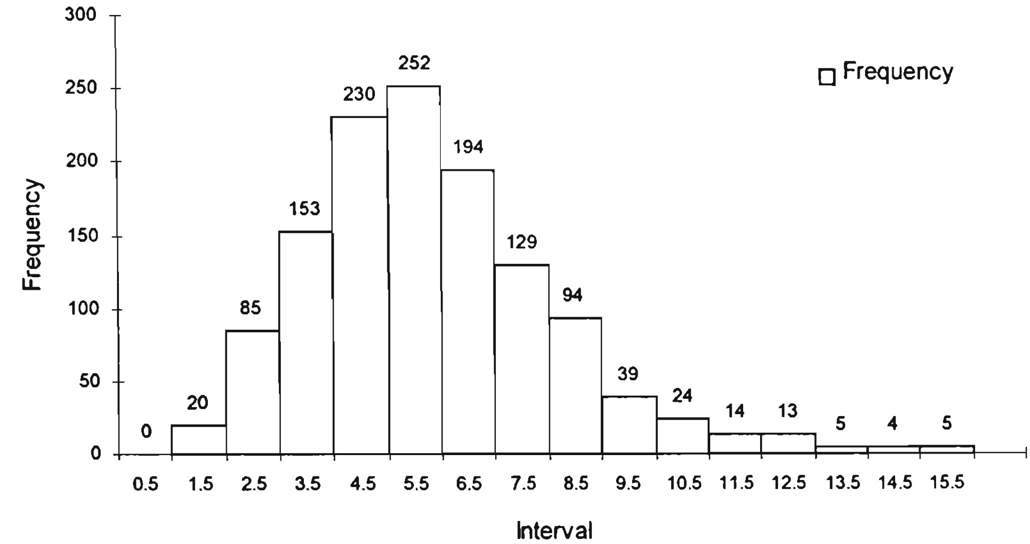


Figure F.12. Histogram of import flow time data with a cell width of 1 minute.

F.8. Export container flow time in North Park

The data collected on the export container flow time is shown in Figure F.13 and is used for model validation process.

Data and histogram summary

Number of data points =379
Max data value =17 minutes
Sample stad. Dev. =2.09
Number of intervals =17

Min data value =1 minute
Sample mean =5.56 minutes
Histogram range =0.5 to 17.5

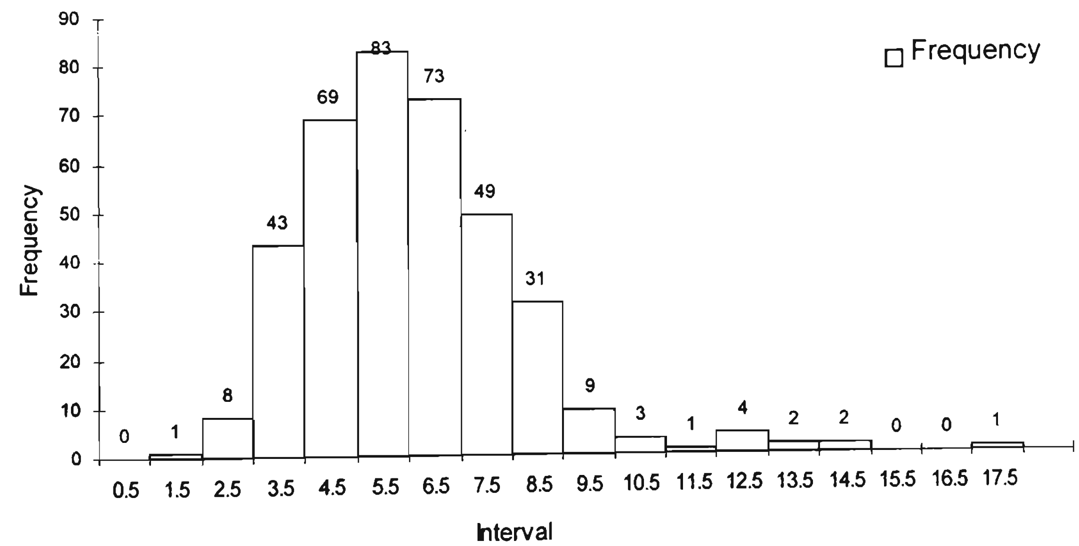


Figure F.13. Histogram of export container flow time data with a cell width of 1 minute.

APPENDIX G

Table G.1. Distances in the straddle network in North Park.

Serial number	Identifier	Number of zones	Length of each zone (m)	Total length (m)
1	1X29X	3	5	15
2	2X23X	3	5	15
3	3X22X	3	5	15
4	4X21X	3	5	15
5	5X20X	3	5	15
6	6X19X	3	5	15
7	7X18X	3	5	15
8	8X17X	3	5	15
9	9X16X	3	5	15
10	10X15X	3	5	15
11	11X14X	3	5	15
12	12X13X	3	5	15
13	13X14X	3	5	15
14	14X15X	3	5	15
15	15X16X	3	5	15
16	16X17X	3	5	15
17	18X19X	3	5	15
18	19X20X	3	5	15
19	20X21X	3	5	15
20	21X22X	3	5	15
21	22X23X	3	5	15
22	23X24X	3	5	15
23	13X75X	3	4	12
24	14X76X	3	4	12
25	15X77X	3	4	12
26	16X78X	3	4	12
27	17X79X	3	4	12
28	18X80X	3	4	12
29	19X81X	3	4	12
30	20X82X	3	4	12
31	21X83X	3	4	12
32	22X84X	3	4	12
33	23X85X	3	4	12
34	24X86X	3	4	12
35	75X76X	3	5	15
36	76X77X	3	5	15
37	77X78X	3	5	15
38	78X79X	3	5	15
39	79X80X	3	5	15
40	80X81X	3	5	15
41	81X82X	3	5	15
42	82X83X	3	5	15
43	83X84X	3	5	15
44	84X85X	3	5	15
45	85X86X	3	5	15
46	25X86X	10	10	100
47	25X26X	2	12	24
48	26X27X	2	12	24
49	27X98X	3	5	15
50	25X61X	3	5	15

Table G.1. Distances in the straddle network in North Park (contd.).

Serial number	Identifier	Number of zones	Length of each zone (m)	Total length (m)
51	61X97X	2	12	24
52	97X98X	2	12	24
53	98X28X	33	5	165
54	28X109X	3	5	15
55	109X29X	5	9	45
56	109X57X	3	10	30
57	57X108X	6	10	60
58	28X30X	3	10	30
59	61X30X	5	25	125
60	30X31X	6	10	60
61	57X58X	15	10	150
62	31X102X	2	10	20
63	31X32X	6	10	60
64	32X105X	5	13	65
65	61X105X	6	10	60
66	105X104X	2	10	20
67	102X103X	6	10	60
68	103X104X	5	13	65
69	102X34X	7	10	70
70	34X58X	3	5	15
71	58X59X	3	4	12
72	59X60X	3	5	15
73	34X60X	3	4	12
74	34X106X	6	9	54
75	106X107X	2	9	18
76	35X36X	2	9	18
77	106X35X	3	5	15
78	35X62X	7	8	56
79	60X63X	5	25	125
80	62X63X	3	4	12
81	62X104X	7	10	70
82	63X64X	3	5	15
83	62X39X	3	5	15
84	39X64X	3	4	12
85	25X33X	6	10	60
86	33X99X	2	10	20
87	99X39X	7	10	70
88	33X37X	6	10	60
89	37X38X	6	10	60
90	99X100X	6	10	60
91	100X101X	6	10	60
92	39X40X	12	10	120
93	64X65X	12	10	120
94	85X74X	2	10	20
95	74X38X	4	10	40
96	38X101X	2	10	20
97	101X40X	7	10	70
98	40X44X	3	5	15
99	65X66X	3	5	15
100	65X40X	3	4	12
101	44X66X	3	4	12
102	84X41X	2	10	20
103	74X41X	3	5	15

Table G.1. Distances in the straddle network in North Park (contd.).

Serial number	Identifier	Number of zones	Length of each zone (m)	Total length (m)
104	41X42X	4	10	40
105	42X94X	2	10	20
106	94X44X	7	10	70
107	44X48X	15	7	105
108	66X67X	15	7	105
109	94X95X	7	7	49
110	95X96X	8	7	56
111	42X43X	7	7	49
112	43X47X	8	7	56
113	46X41X	5	7	35
114	46X82X	2	10	20
115	45X46X	10	7	70
116	77X45X	2	10	20
117	45X47X	4	10	40
118	47X49X	3	5	15
119	47X96X	2	10	20
120	96X48X	7	10	70
121	87X76X	2	10	20
122	45X87X	3	5	15
123	87X49X	7	10	70
124	49X91X	2	10	20
125	91X51X	4	10	40
126	48X51X	3	5	15
127	67X68X	3	5	15
128	48X67X	3	4	12
129	51X58X	3	4	12
130	49X50X	3	10	30
131	50X52X	3	10	30
132	91X92X	3	10	30
133	92X93X	3	10	30
134	51X53X	9	10	90
135	68X69X	9	10	12
136	53X69X	3	4	12
137	52X93X	2	10	20
138	52X70X	3	5	15
139	70X88X	2	10	20
140	93X53X	4	10	40
141	53X71X	3	5	15
142	69X72X	3	5	15
143	71X72X	3	4	12
144	88X71X	11	5	55
145	71X56X	27	5	135
146	70X54X	13	5	65
147	54X55X	14	5	70
148	88X89X	13	5	65
149	89X90X	14	5	70
150	55X90X	2	10	20
151	90X56X	11	5	55
152	72X73X	27	5	135
153	56X73X	3	4	12

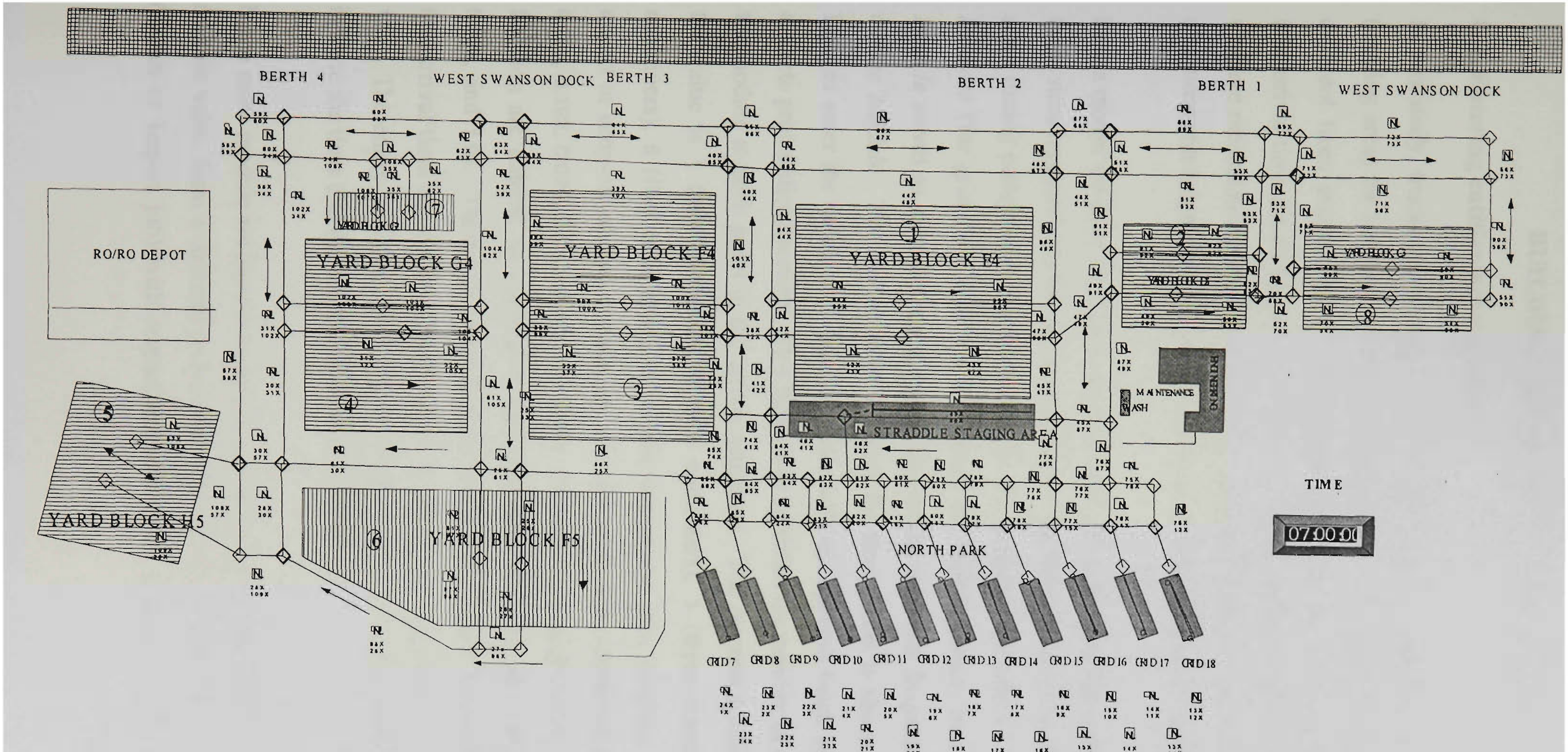


Figure G.1. A schematic of the container handling system as portrayed by ARENA.

BUILDING THE MODEL USING ARENA

G.1. Entering entities into the model

In this study, trucks are coming to the North Park grid, which consists of 12 grids (parking area) for loading and unloading of trucks. Arrival of a truck on each grid is different from another grid. To simplify this task, we have modelled the same interarrival time for all 12 grids. In order to obtain a single interarrival time on grids, we have measured the time between truck arrival on each grid and then added all the measurements to get the final interarrival time, which is the same for all grids.

In this model we have 12 distinct streams of arriving entities (assuming all entities in the system represent trucks that are waiting for processing) in our model, each with its same timing pattern (see Figure G.2). For this purpose, we used 12 separate *Create Modules* (for grid 7 to grid 18) to generate the arriving truck, because the *Create Module* serves as an entity source point and model segments frequently begin with a *Create Module.* The Arena block diagram for this system is shown in figure G.2. Entities enter the model at *Create Modules* with the operand batch size specified by discrete probability function. This batch size specifies the number of entities to enter the module at each point in the arrival sequence. The discrete function returned by the value is 1 (one container), 2 (two containers), 3 (three containers), 4 (four containers), 5 (five containers), or 6 (six containers) jobs (request for pick-up of export or drop-off of import container on each grid) with respective probabilities of 0.758, 0.192, 0.028, 0.015, 0.066, and 0.001. However, the probabilities in the discrete function are entered as cumulative probabilities (i.e., as 0.758, 0.950, 0.978, 0.993, 0.999, and 1.0). Thereafter, entities enter the model at the *Create Module* with an interarrival time based on a lognormal distribution i.e., 1.5 minutes + Lognormal (15.2, 12.8). The entity will have two initial attribute values. The first attribute Arrival Time is set to the time that the entity was created (TNOW).

In the same module we have assigned the second attribute MoveType which is set to a random value from a discrete probability distribution. The value assigned is 1 or 2 (export or import job) with respective probabilities 0.49 and 0.51. Note that the probability values in the discrete distribution are specified as cumulative values. Entities generated from the modules have no initial picture for animation purposes.

G.2. Request of straddle carriers and transfer of export containers

The entities from *Create Modules* then enter *Choose modules* where the arriving entities take the first branch condition; that is, if the attribute MoveType = 1 (export job), the entities are sent to *Request modules*. If this condition fails, the entities are sent to *Allocate modules*. At the *Request modules*, an arriving entity requests a transporter called straddle. We have multiple straddles in the terminal system. The assignment of straddles to entities is based on a transporter selection rule, which dictates which one of the straddle units will meet the request. In our model the preferred order rule makes sense, because the present system has a selection rule that always attempts to select the straddle with the lowest number. The selection is based on the straddle's station and the entity's current station. Once a straddle unit is allocated to the entity the unit number is stored in the attribute Straddle #. This attribute value is used in other modules as the unit number to gain control of a specific unit of straddle. In the same module, the priority is assigned based on the specified straddle unit to be requested or seized among competing modules when entities are waiting for the same straddle.

To accomplish first in first out, we have used the attribute Arrival Time as the request priority. This will create the first in first out effect in the model because the creation time of the entity is stored in attribute Arrival Time. Entities in modules requesting the straddles with first in will have priority over the entities waiting at this module. At this module, an arriving entity held in the queue, namely G7_Q for entities from Grid 7 until a straddle becomes available. Similarly, names G8_Q, G9_Q, G10_Q, G11_Q, G12_Q, G13_Q, G14_Q, G15_Q, G16_Q, G17_Q, and G18_Q are assigned for entities held in the queues on Grid 8, Grid 9, Grid 10, Grid 11, Grid 12, Grid 13, Grid 14, Grid 15, Grid 16, Grid 17, and Grid 18 of North Park. Queue characteristics for requesting straddle unit such as # in queue statistics and time in queue statistics are marked on queue assignment based on FirstIn-FirstOut ranking rule. The storage identity called Grid7_S provides a reference to the animation.

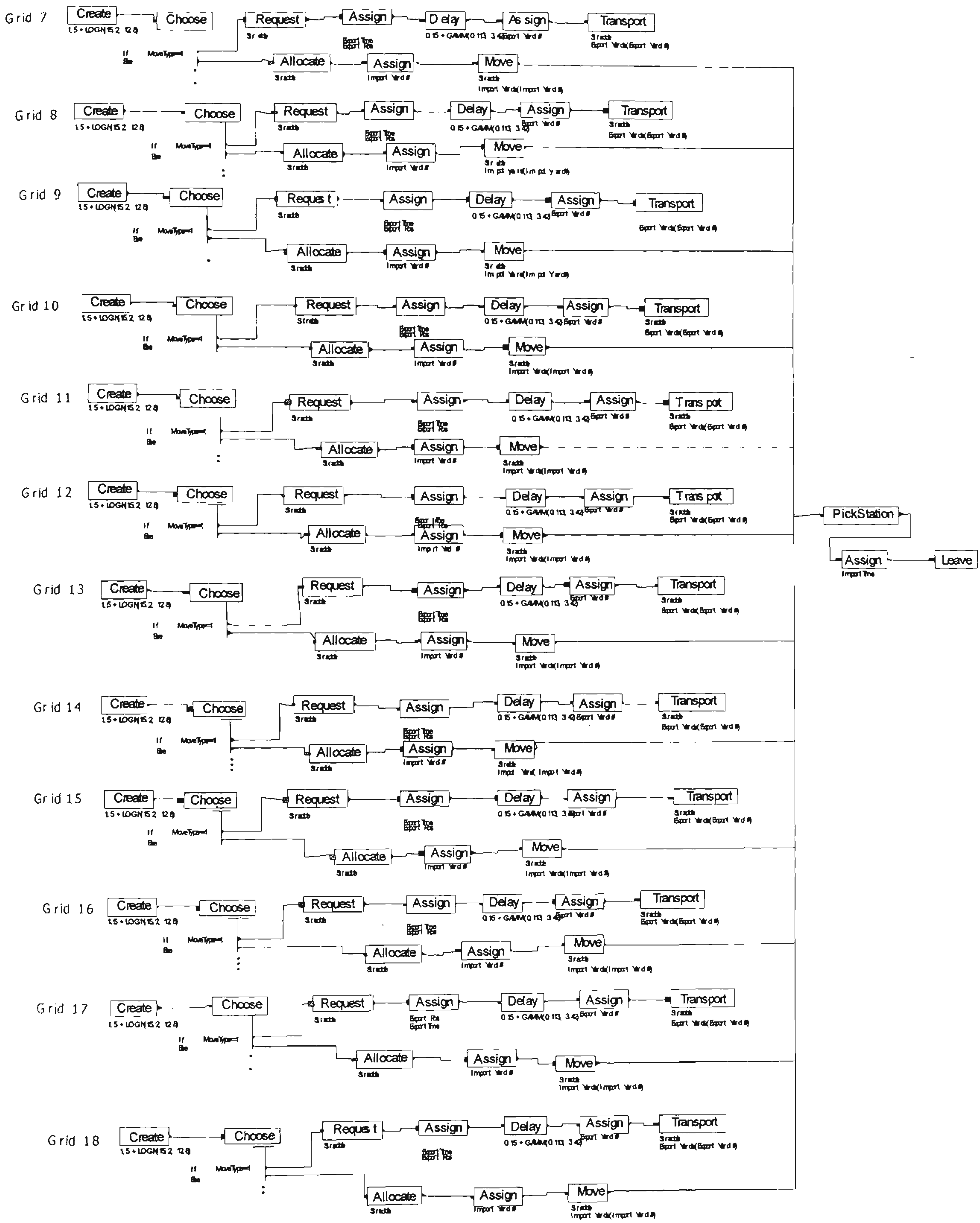


Figure G.2. Block diagrams used in model for truck arrival, straddle request, and straddle allocation logic.

Similar storage identities are GRID8_S, Grid9_S, Grid10_S, Grid11_S, Grid12_S, Grid13_S, Grid14_S, Grid15_S, Grid16_S, Grid17_S, and Grid18_S for other grids.

Once allocated a straddle for transport, the entities then move out of the *Request Module* to an *Assign Module* where two assignments are made. The first is Export Pics (for export container) for animation. The second assignment is to record the time, for later statistical collection, that is, the Export Job Time. The attribute ExportTime is assigned a value as TNOW, which is an ARENA variable that gives the current simulation clock time.

The entity is then sent to the following *Delay Module* where it is delayed by a time that is equal to pick-up time i.e., 0.15 minutes + Gamma (0.113, 3.42) of export containers; during this time, the entity retains ownership and control of the straddle unit.

After the delay for pick-up entity then enters an *Assign Module*, where the attribute Export Yard # is assigned a value from a discrete probability function. The value returned by this function is a 1, 2, 3, 4, 5, 6, 7, or 8 with respective probabilities of 0.03, 0.05, 0.14, 0.29, 0.02, 0.40, 0.01, and 0.06. Here the probabilities in the Discrete function are entered as cumulative probabilities (i.e., as 0.03, 0.08, 0.22, 0.51, 0.53, 0.93, 0.94, and 1.0).

The entity then arrives at the *Transport Module* where it and its accompanying straddle are transferred to the next destination station derived from the expression Export Yards (Export Yard #) on its way to the final drop-off position in yard blocks. If no straddles are available when the requesting entity arrives at G7_Q, G8_Q, G9_Q, G10_Q, G11_Q, G12_Q, G13_Q, G14_Q, G15_Q, G16_Q, G17_Q, or G18_Q, the entity remains in the queue until a straddle is freed in the model. If other entities are already waiting when an entity arrives at the queue named G7_Q, G8_Q, G9_Q, G10_Q, G11_Q, G12_Q, G13_Q, G14_Q, G15_Q, G16_Q, G17_Q, and G18_Q, then the arriving entity simply waits on grids until it progresses to the front of the queues and its request is granted. The specific unit is based on the attribute Straddle # which is referenced to choose a straddle unit.

G.3. Allocation of straddle carrier and transfer of import container

We recall at *Choose Module* in the previous section where the first branch condition fails e.g., MoveType = 2, the entity is sent to the *Allocate Module*. The *Allocate Module* assigns a straddle to an entity without moving it to the entity's station location. The entity then has control of the straddle to move it to a particular pick-up location in yard blocks. The straddle selection rule preferred order (POR) is used to determine which of the straddle units will be assigned to the entity. Similarly entities requesting straddles get the straddle first, based on priority. The details of priority are discussed in the previous section. The entities attribute straddle # will store the unit number of straddle that is allowed to the entity. The creation time of the entity is stored in attribute Arrival Time. If there are multiple entities (say from Grid 7 to Grid 18) attempting to allocate the straddle, ARENA uses the POR rule to determine which entity is allocated to the straddle. The POR rule is applied because the allocation priority is identical (default value of 1) for all 12 queues such as P7_Q, P8_Q, P9_Q, P10_Q, P12_Q, P13_Q, P14_Q, P15_Q, P16_Q, P17_Q, and P18_Q. All pick-up (export jobs) or drop-off requests (Import jobs) are separated on each grid and also assigned two different queues for waiting for service of straddles. In each queue, # in queue statistics and time in queue statistics are assigned or marked for later statistical collection, so that time waiting import jobs are waiting for service of straddles and number of jobs in queue for service of straddles is based on FirstIn FirstOut ranking rule.

Once allocated a straddle, the entities are sent to an *Assign Module* where one assignment is made. The assignment attribute Import Yard # is set to a random value from a discrete probability distribution. The value assigned is 1, 2, 3, 4, 6, 7, or 8 with respective probabilities 0.565, 0.006, 0.225, 0.156, 0.025, 0.014, and 0.009. Here the probabilities in the discrete function are entered as cumulative probabilities i.e., as 0.565, 0.571, 0.796, 0.952, 0.977, 0.991, 1.0.

The entities then transfer through the *Move Module*, which advances a straddle from its current position to Yard blocks without moving the controlling entity to yard blocks. The controlling entity remains at its current module (i.e., *Create Modules*) location until the straddle arrives at yards for pick-up of import container. At that time, entity will be able to move from one module to another module in the model.

At *Move Module* storage identifier G7_S, G8_S, G9_S, G10_S, G11_S, G12_S, G13_S, G14_S, G15_S, G16_S, G17_S, and G18_S provides a reference to an animation layout and indicates where the entity symbol will reside during the actual move operation. The transporter name straddle, unit number Straddle # correspond exactly to the specific straddle previously allocated. The straddle destination is expressed by an expression Import Yards (Import Yard #).

Entities that represent import jobs are then directed to the *PickStation Module*. The *PickStation Module* allows us to select from among a list of import yard destination stations based on conditions involving the number of entities at those Import yard Stations in yard blocks. PickStation name WhichImportYard is assigned for selection of import stations. We used this module with a condition that selects import station in yards based on minimum number en route to station and number in queue.

The stations considered in the selection process are Import1, Import2, Import3, Import4, Import5, Import6, Import7, and Import8. The queues considered in the selection process are Import1_Q, Import2_Q, Import3_Q, Import4_Q, Import5_Q, Import6_Q, Import7_Q, and Import8_Q for station evaluation. The corresponding station will be selected and stored in the attribute PickStation_att.

The entity is then sent to an *Assign Module* where an assignment is made to the attribute ImportTime. The value of the assignment is entered as TNOW, which is an ARENA variable that gives the current simulation time and used to record the time, for later statistical collection of Import Job Time (import container transfer time). Upon completion of the assignment of ImportTime, the entity is sent to the *Leave Module* where entity transfers to different stations based on an expression on PickStation_att. The station value is an attribute of the entity that was set in *the PickStation Module*.

G.4. Export jobs processing logic in yard blocks

An entity represents export container arriving at the export yard station 1Y of *Advanced Server* module (see Figure G.3) to wait for one of the rows. Yard rows have been included in the resource set 1Y_S.

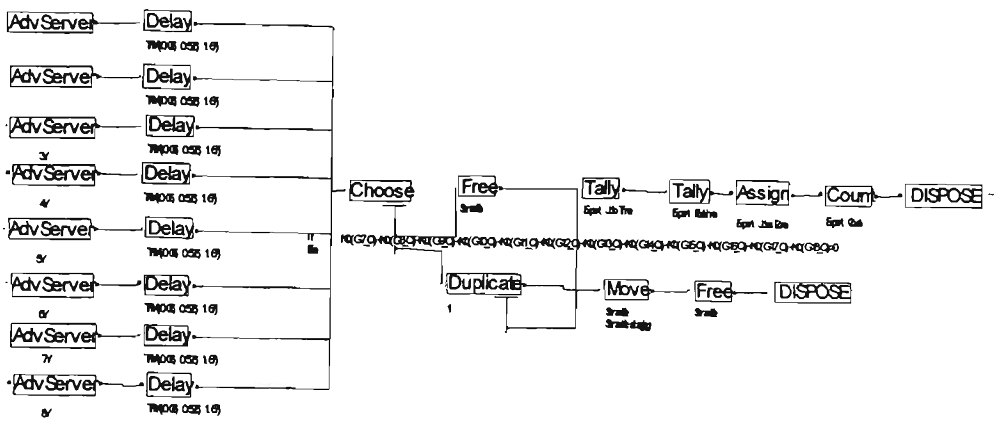


Figure G.3. Model listings for export container drop-off logic in yards.

We choose the cyclical rule so that if rows are available, the row will be selected from the members of the set cyclically. The row position of export yard block that the entity receives will be stored in the attribute SetAttribute_1Y. The resource set specifies the name of an attribute in which to store the member of the resource set that was seized. For example, if a resource set 1Y_S has 27 members and the third member Y1_3 (row) was seized this attribute is set to 3. This attribute might be used later as a set index for releasing the resource. Also note that we have entered a processing time of 0.

Similarly export containers arriving at stations 2Y, 3Y, 4Y, 5Y, 6Y, 7Y, and 8Y are to wait for one of the rows at these yard stations. Those rows have been included in the resource sets such as resource set 2Y_S, 3Y_S, 4Y_S, 5Y_S, 6Y_S, 7Y_S, and 8Y_S.

To define these rows at Export yard stations completely, required a *Sets Module* and 182 *Resource Modules* [see Figures G.9(a) and G.9(b)]. These resource modules were used to define the row capacity (no of ground positions) upon seizing an available row, an export container exits the *Advanced Server Module* by connecting to *Delay*

Module. The modules we used to model rows are shown in Figures G.9(a) and G.9(b).

Export containers (entities) are then delayed by the *Delay* module by a time that is triangularly distributed with a minimum of 0.06 minutes, mode of 0.526 minutes, and maximum of 1.67 minutes for drop-off containers in yards. At the completion of the delay, export containers then pass through the *Choose Module*.

The *Choose Module* after drop-off of containers determines whether any requests are currently in G7_Q, G8_Q, G9_Q, G10_Q, G11_Q, G12_Q, G13_Q, G14_Q, G15_Q, G16_Q, G17_Q, and G18_Q. Because all export container requests wait in these queues until a straddle is allocated, the export container (entity) need only check to see if there are requesting entities, i.e., NQ(G7_Q) + NQ(G8_Q) + NQ(G9_Q) + NQ(G10_Q) + NQ(G11_Q) + NQ(G12_Q) + NQ(G13_Q) + NQ(G14_Q) + NQ(G15_Q) + NQ(G16_Q) + NQ(G17_Q) + NQ(G18_Q) > 0, the entity is then sent to *Free Module* where the straddle is freed. Export containers then pass through the two *Tally Modules*. The first *Tally Module* records the Export Job Time (Actual transfer time by straddles), and the second *Tally Modules* records Export Flow Time in the system. Then the export container passes through *Assign Module* where a variable Export Jobs Done assigns a value of Export Jobs Done + 1. Before exiting from the model, export containers are sent to the *Count Module*. The *Count Module* increases the value of the counter named Export Count (Export Container) by 1. The export containers are then disposed of by *Dispose Module*.

If there are no export containers (requesting entities) i.e., NQ(G7_Q) + NQ(G8_Q) + NQ(G9_Q) + NQ(G10_Q) + NQ(G11_Q) + NQ(G12_Q) + NQ(G13_Q) + NQ(G14_Q) + NQ(G15_Q) + NQ(G16_Q) + NQ(G17_Q) + NQ(G18_Q) == 0, the entity is sent to *Duplicate* Module. This module allows us to make duplicates (Clones) of the entering export container. The original export container leaves the module by the exit point (located at the right of the module handle). At this stage, the original export container (entity) that controls the straddle sends to *Move Module*. This *Move Module* is transporting the empty straddle to station, Straddle Staging when the straddle arrives at Straddle Staging (parking area for straddles), the entity is sent to *Free Module* where the straddle is freed and the entity is disposed of by *Dispose Module*. The duplicated entities leave the *Duplicate Module* by the exit points below the module handle. In this module only one entity is duplicated which is an exact replica of the original entity. The duplicate entity is sent then sent to the *Tally-Tally-Assign-Count-Dispose* sequence before exit from the model.

G.5. Import job request processing logic

An entity (import request) arriving at the *Advanced Server Module* enters Import1 station (see Figure G.4). Here an entity requires a row position in Import Yards station. Although export and import yards are the same in the real system, we have simplified the model by separating the export and import yard stations, because ARENA does not allow us to use same station name twice for export and import yard stations. The resource set Import1_S specifies the name of an attribute SetAttribute_Imp1 in which to store the member of the resource set that was seized. A cyclical rule will be used to determine which row position will be assigned to the entity. We have entered a processing time of 0. Similarly import containers arriving at stations Import2, Import3, Import4, Import5, Import6, Import7, and Import8 have to wait for one of the rows at these Import Yard stations. These rows have been included in the resource sets such as Import2_S, Import3_S, Import4_S, Import5_S, Import6_S, Import7_S, and Import8_S. To define these rows at Import Yard Stations completely required a *Set Module* and 182 number of *Resource Modules* [see Figures G.10(a) and G.10(b)].

These resource modules were used to define the row capacity (number of ground slots). Once an import container has been allocated in import yards, it will then be transferred to the *Delay Modules* which imposes a delay for pick-up of import containers. The time required to pickup is gamma distributed with an expression 0.15 + Gamma (0.113, 3.42). Upon completion of the delay, the entities then pass through the *Assign Module* where the picture is set to picture name Import Pics.

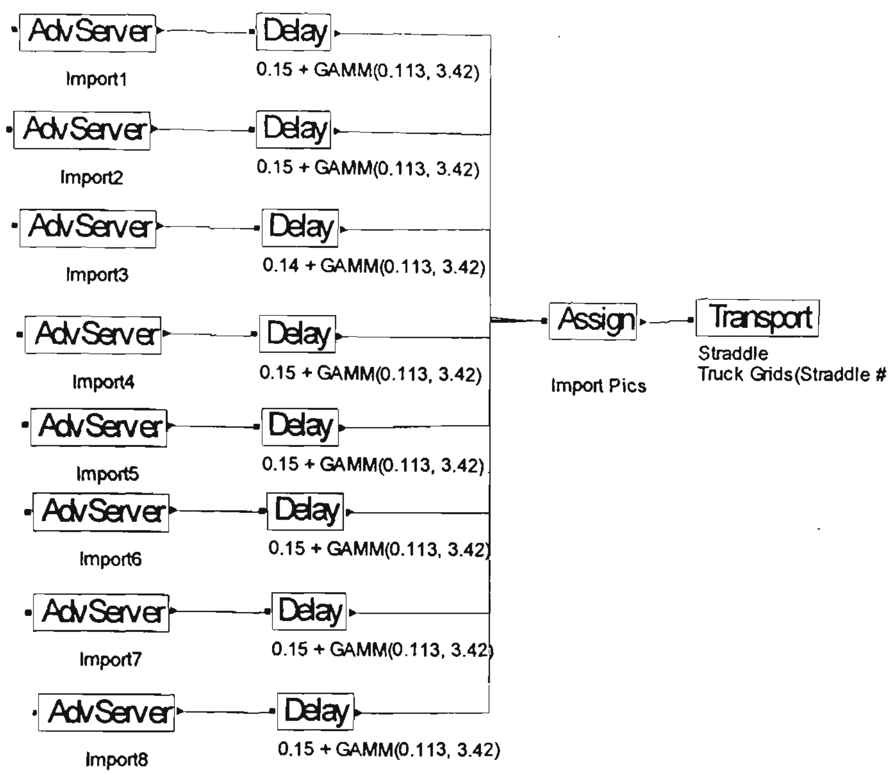


Figure G.4. Model listings for import container pick-up in yard blocks.

The entity which holds previously allocated straddles is sent to the *Transport Module*. This is used to transport both the entity and the previously allocated straddle. Then the import container is transported to the destination station derived by using an expression Truck Grids (Straddle #) on its way for the final drop-off position on grids. Note that the import container will arrive at its destination station (Grids) at the same time that the straddle arrives at its destination.

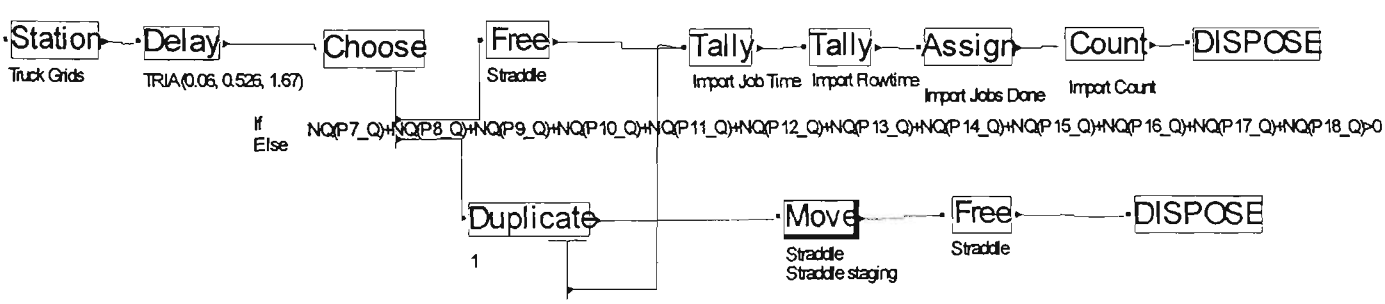


Figure G.5. Model listings for import container drop-off logic on truck grids.

Import containers after arriving to the *Station Module* (see Figure G.5) use station set Truck Grids. Truck Grids contain 12 individual stations, Grid 7, Grid 8, Grid 9, Grid 10, Grid 11, Grid 12, Grid 13, Grid 14, Grid 15, Grid 16, Grid 17, and Grid 18. All entities that are transferred to any member of the station set Truck Grids are sent to this module. Attribute SetIndex is used to store the station set for an entity entering this module.

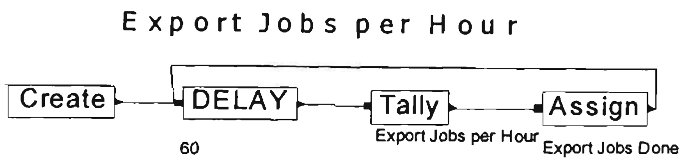
Import containers are then sent to *Delay Module*, which imposes delay for drop-off on waiting trucks. This drop-off time is equal to triangular distribution with a minimum of 0.06 minutes, mode of 0.526, and maximum of 1.67 minutes [i.e., Triangular (0.06, 0.526, 1.67)].

Then the arriving entities after drop-off delay will take the first branch of *Choose Module* that are evaluated to true. If the condition NQ(P7_Q) + NQ(P8_Q) + NQ(P9_Q) + NQ(P10_Q) + NQ(P11_Q) + NQ(P12_Q) + NQ(P13_Q) + NQ(P14_Q) + NQ(P15_Q) + NQ(P16_Q) + NQ(P17_Q) + NQ(P18_Q) > 0, then entities are transferred to *Free Module*. This release the entity's most recently allocated straddle unit. Then entities then pass through two *Tally Modules*. The first *Tally Module*, the value of current simulation times (TNOW) minus the value of the attribute ImportTime for the entity records in the Import Job Time. The second *Tally module* records the Import FlowTime. The next sequence of entity is arrival at *Assign Module* entity's variable Import Jobs Done is set to the Import Jobs Done + 1. The entity then arrives at *Count Module*, which increases the counter named Import Count by 1 each time an entity arrives at this module. After executing the count module, entities are disposed of at the *Dispose Module*.

If there are no import container requests in the model i.e., NQ(P7_Q) + NQ(P8_Q) + NQ(P9_Q) + NQ(P10_Q) + NQ(P11_Q) + NQ(P12_Q) + NQ(P13_Q) + NQ(P14_Q) + NQ(P15_Q) + NQ(P16_Q) + NQ(P17_Q) + NQ(P18_Q) == 0, the entity is sent to *Duplicate module*. The original entity is sent to the module connected to the module exit point where entity transfers to the *Move Module*. At this module, an empty straddle is moved to the station named Straddle Staging (straddle parking area). Then the entity passes through the *Free Module* where the most recently allocated straddle unit will be released. If there are no waiting entities at the time the straddle unit is freed, the straddle will wait idle at the Straddle Staging station. The duplicate entity (exact replicas of the original entity) is then sent to the *Tally-Tally-Assign-Count-Dispose Module* sequence before exit from the model.

G.6. Export Jobs per hour logic

The *Create Module* generates a single entity in each batch creation to trigger this logic loop (see Figure G.6). Entities have no physical meaning and are normally referred to as logical entities. Thereafter, entities are created with no interarrival time. Entities generated from this create module will have no special initial attribute values, nor will they have an initial picture to be used for animation.



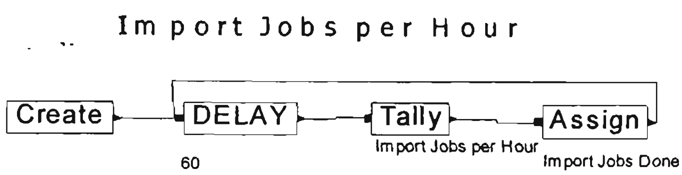


Figure G.6. Module listings for export and import jobs per hour.

Then the logical entity arriving at *Delay Module* delays by 60 minutes (the length of each hour) duration time. The entity then passes through *Tally Module* where observation Export Jobs per Hour is defined as an expression Export Jobs Done which is recorded for statistical calculation. Entity then passes through *Assign module* where the user-defined variable Export Jobs Done is equal to 0 and then it returns to the first delay modules to update the delay for next time period (every hour).

G.7. Import Jobs per hour logic

The logical entity generates at a *Create Module* and then passes through a *Delay Module* where it delays by 60 minutes. Upon completion of delay entity transfers to *Tally Module* where observation Import Jobs per Hour is defined as an expression Import Jobs Done. Before looping the logical entity then passes through *Assign module* where the variable Import Jobs Done is set to 0. The entity then returns to the first delay module to update the delay for the next time period.

G.8. Modelling of straddle carrier failures

We have added an independent sub-model to the model which essentially provides a failure loop. Figure G.7 shows a block diagram for a failure loop for our model.

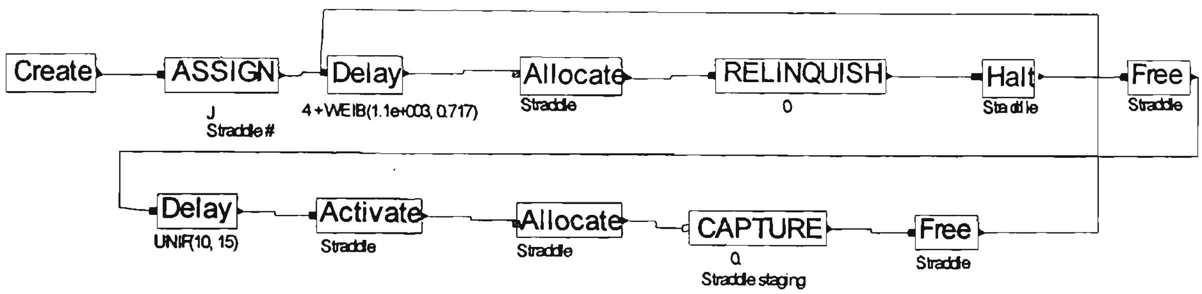


Figure G.7. Model listings for straddle failure sub-model logic.

The single *Create Module* creates 2 entities at time 0.0. The first entity proceeds to the *Assign Module* where the integer system variable, J, is increased by 1 and the resulting value is then assigned to the entity's attribute Straddle #. Because ARENA initialises the value of J to 0 at the start of each run, the first entity has a value of 1 assigned to its attribute named Straddle # and the second a value of 2. The Straddle # is used to identify which straddle is to fail. All two entities are then sent directly into the failure loop. Each entity in the failure loop operates independently.

An entity is first delayed at *Delay Module* by an amount of time generated from Weibull distribution i.e., 4 minutes + Weibull (1.1e+003, 0.717); this time period represents the time between failures (break down). The entity then passes to the *Allocate Module*, *Relinquish Module*, and *Halt Module*, which attempts to set the status of the specified straddle unit to an inactive one. The first entity is placed in the Failure_Q of *Allocate Module* having the highest priority of all hold modules requesting the straddle. When this entity has control of the failed straddle, it performs the remaining logic. The second entity activates the failed straddle, after the first entity is placed in Failur_Q. Because the only function of this second entity is to activate the straddle, it is immediately disposed of. If the specified straddle unit is currently busy, its status is set to inactive as soon as it is freed. In the *Relinquish Block*, the number to relinquish is set to 0, because in our model, the straddle is not controlling any zone which has been considered in the initial stage of formulating the model. Here we can recall that length of straddle is set to zero in our model. If the straddle repair is lengthy, the maintenance staff often physically remove the straddle from the route so that it does not block other straddle travel. Usually management replaces the failed straddle with a spare straddle from its reserve pool within a minimum of 10 minutes up to a maximum 15 minutes. To model this, the entity enters the next *Delay Module* where it is delayed by an amount of time that represents the replacement time of straddles. This delay is given by a Uniform distribution with a minimum of 10 minutes and a maximum of 15 minutes [i.e., Uniform (10, 15)].

After the straddle is replaced a similar reverse puts the straddle back on the path and changes its status to active. The second entity activates the failed transporter, after the first entity is placed in the queue because the only function of this second entity is to activate the straddle. After this delay, the entity enters the *Activate Module* where the specified straddle unit is set to active. The entity then passes *Allocate-Capture-Free* sequence until the straddle has been on the straddle route. In the *Capture Block* the quantity to capture is set to zero because it does not require any zones. Hence, it can move freely and can essentially pass directly over another stopped straddle. In the *Capture Block* the travel destination of the straddle is specified as straddle staging which is associated with an intersection 46X. The entity is then sent back to the start of failure loop.

G.9. Data logic for the model

The data modules required are shown in figure G.8. The *Transporter Module* defines a straddle's operating parameters such as velocity, acceleration and deceleration. In our basic model a velocity of 15 km/hr (4.16 m/sec) is specified for the basic model. The operands, acceleration and deceleration are 0.48 m/sec^2 and 3.44 m/sec^2 which describes the additional time required to start or stop the straddles. There are six straddles positioned on link 45X46X in an active state. The straddle size is set to zero. A home intersection 46X is specified so that it can return when the straddle unit is freed. In order to avoid physical interference between straddles we have specified straddles that have a size of 0, because in real system straddles visit a large number of locations in the terminal.

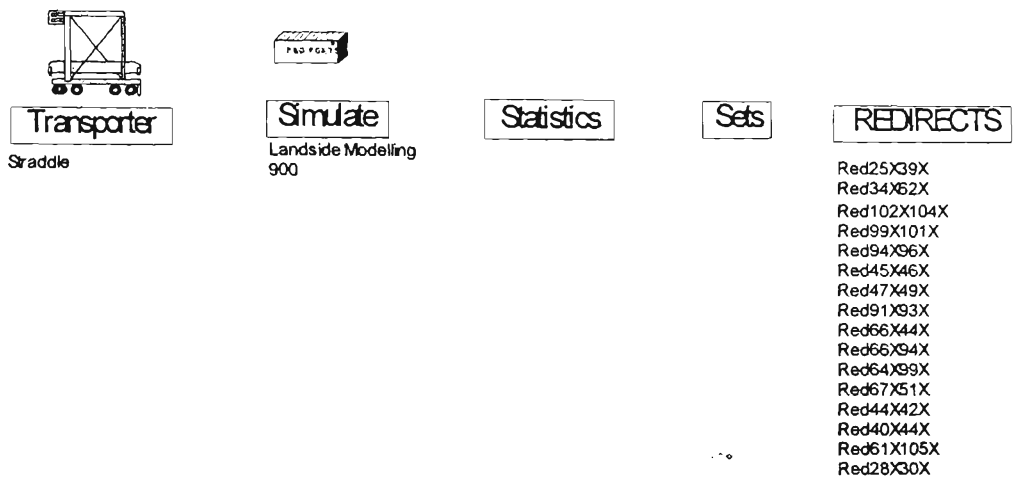


Figure G.8. Data Modules used in model.

The *Statistics Module* is used to define statistics and output data files for analysis. The time-persistent statistics includes the number in queues G7_Q, G8_Q, G9_Q, G10_Q, G11_Q, G12_Q, G13_Q, G14_Q, G15_Q, G16_Q, G17_Q, G18_Q, P7_Q, P8_Q, P9_Q, P10_Q, P11_Q, P12_Q, P13_Q, P14_Q, P15_Q, P16_Q, P17_Q, and P18_Q. Other statistics such as # in export pickup (i.e. summation of G7_Q, G8_Q, G9_Q, G10_Q, G11_Q, G12_Q, G13_Q, G14_Q, G15_Q, G16_Q, G17_Q, G18_Q) and # in import place queue (i.e. summation of P7_Q, P8_Q, P9_Q, P10_Q, P11_Q, P12_Q, P13_Q, P14_Q, P15_Q, P16_Q, P17_Q, P18_Q) are also specified. The straddle utilisation is also collected using this expression MAX (NT(Straddle), 0) * 100/6. Additional statistical information such as Export Jobs per Hour, Import Jobs per Hour, Export FlowTime, Import FlowTime, Export Job Time, Import Job Time are specified. Other additional statistical information such as Export Count and Import Count are specified. Under the output elements of the statistics module queue times in G7_Q, G8_Q, G9_Q, G10_Q, G11_Q, G12_Q, G13_Q, G14_Q, G15_Q, G16_Q, G17_Q, and G18_Q are specified together with queue time in P7_Q, P8_Q, P9_Q, P10_Q, P11_Q, P12_Q, P13_Q, P14_Q, P15_Q, P16_Q, P17_Q, and P18_Q.

The *Set Module* is used to form sets of resources which include the export yard and import yards, truck grids, export yards and import yards stations. We have defined the resource sets such as 1Y_S, 2Y_S, 3Y_S, 4Y_S, 5Y_S, 6Y_S, 7Y_S, and 8Y_S for export yards and Import1_S, Import2_S, Import3_S, Import4_S, Import5_S, Import6_S, Import7_S, and Import8_S for import yards. Having defined our Truck Grids (stations), we have defined the contents of this *Sets Module* to use pick-up and drop-off containers on grids. We also defined two station sets such as Export Yards and Import Yards. They are:

Export Yards: 1Y, 2Y, 3Y, 4Y, 5Y, 6Y, 7Y, 8Y

Import Yards: Import1, Import2, Import3, Import4, Import5, Import6, Import7, Import8

We have placed a total of 364 resource modules (for export and import row) in the model which are shown in Figures G.9(a), G.9(b), G.10(a), and G.10(b).

Animate Modules are used for export count (export container), import count (import container), export flow time, import flow time, export jobs per hour, and import jobs per hour to demonstrate the status of the simulation system graphically. Other animations included are G7_Q, G8_Q, G10_Q, G11_Q, G12_Q, G13_Q, G14_Q, G15_Q, G16_Q, G17_Q, and G18_Q for export jobs and P7_Q, P8_Q, P9_Q, P10_Q, P11_Q, P12_Q, P13_Q, P14_Q, P15_Q, P16_Q, P17_Q, and P18_Q for import jobs for service of straddles.

Table G.2. Redirect routes in straddle layout.

Route name	Beginning intersection	Ending intersection	Next intersection specifying the actual redirect
Red25X39X	25X	39X	61X
Red34X62X	34X	62X	60X
Red102X104X	102X	104X	34X
Red99X101X	99X	101X	39X
Red94X96X	94X	96X	44X
Red45X46X	45X	46X	77X
Red47X49X	47X	49X	96X
Red91X93X	91X	93X	51X
Red66X44X	66X	44X	67X
Red66X94X	66X	94X	67X
Red64X99X	64X	99X	65X
Red67X51X	67X	51X	68X
Red44X42X	44X	42X	48X
Red40X44X	40X	44X	65X
Red61X105X	61X	105X	30X
Red28X30X	28X	30X	109X

In the real system an empty straddle should not pass through yard blocks if there is no request to pick-up or drop-off containers. To avoid the entry of empty straddles inside the yard blocks, we have specified the alternative route, which can be viewed as a bypass in *Redirect Element*. This is most essential to prevent any possible waiting because of blocking at pick-up or drop-off intersections in yards. This *Redirect Element* provides the beginning, ending, and next-intersection identities which specify the actual redirect. Table G.2 shows the beginning intersection identity (ID), ending intersection ID, and Next Intersection ID for our model. We have placed *Simulate Module* with the replication length specified as 900 minutes (corresponding to a 15 hr shift operation) and with a total 30 replications.

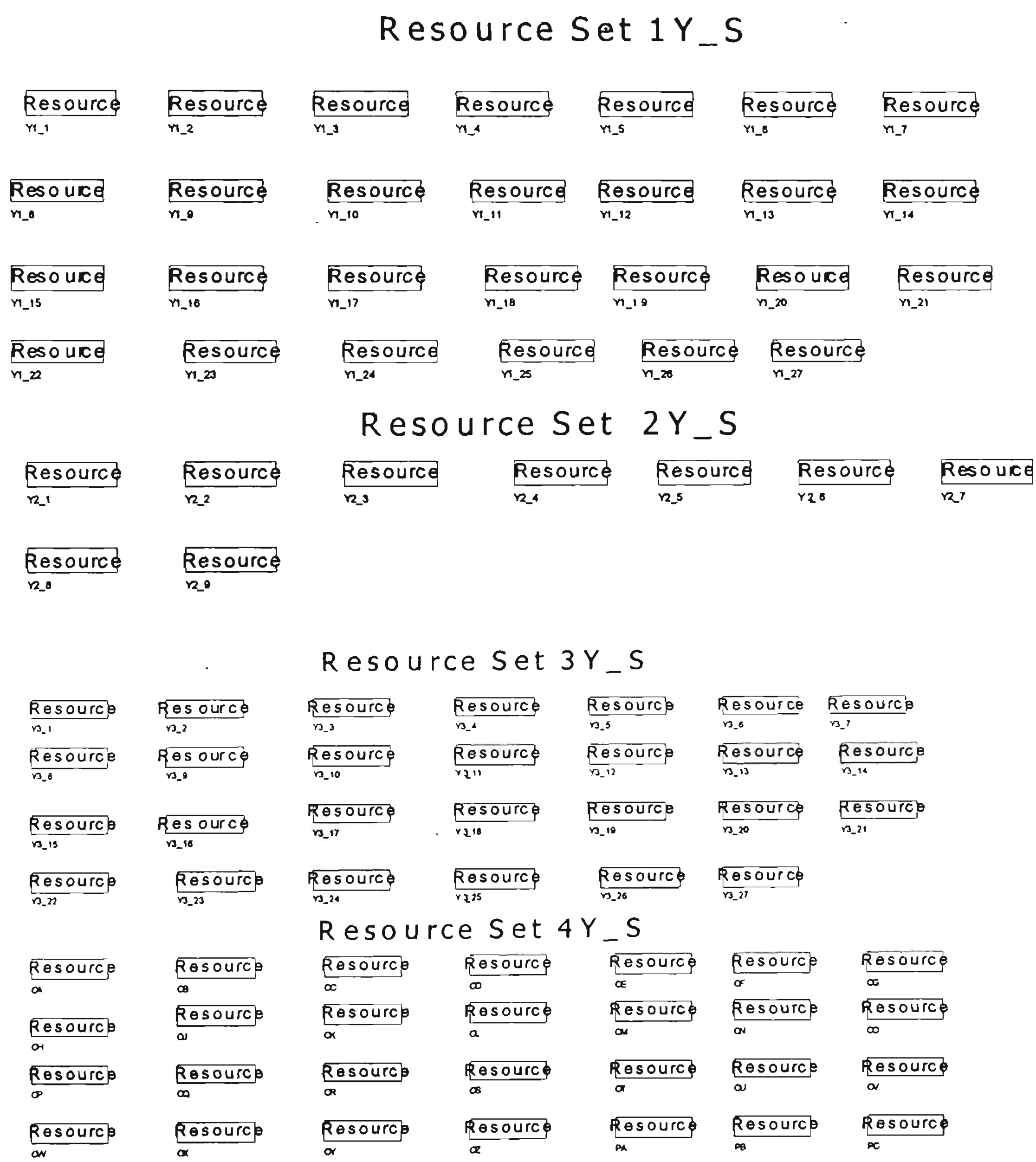


Figure G.9(a). Resource sets for export container drop-off process in yard blocks.

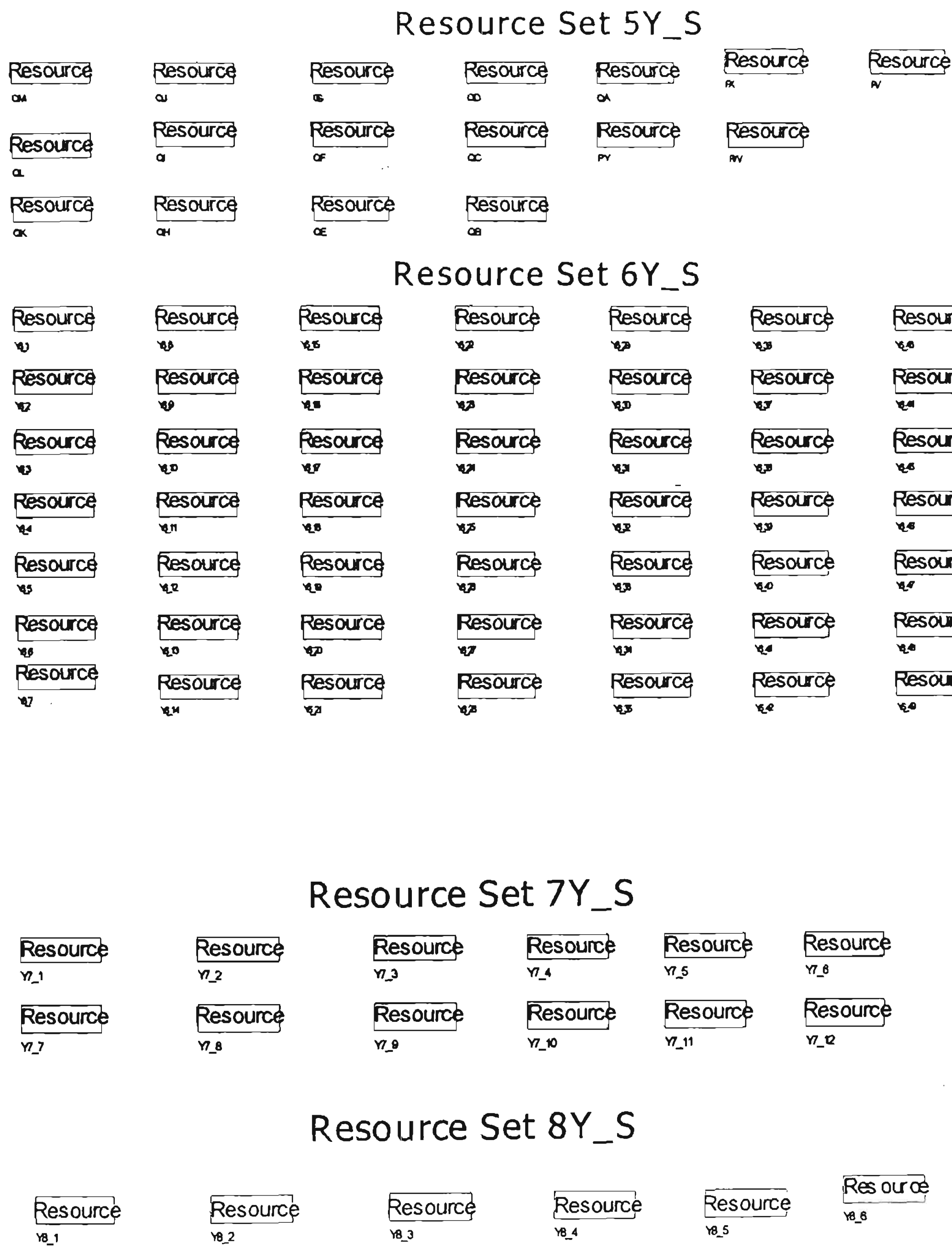


Figure G.9(b). Resource sets for export container drop-off process in yard blocks.

Figure G.10(a). Resource sets for import container pick-up process in yard blocks.

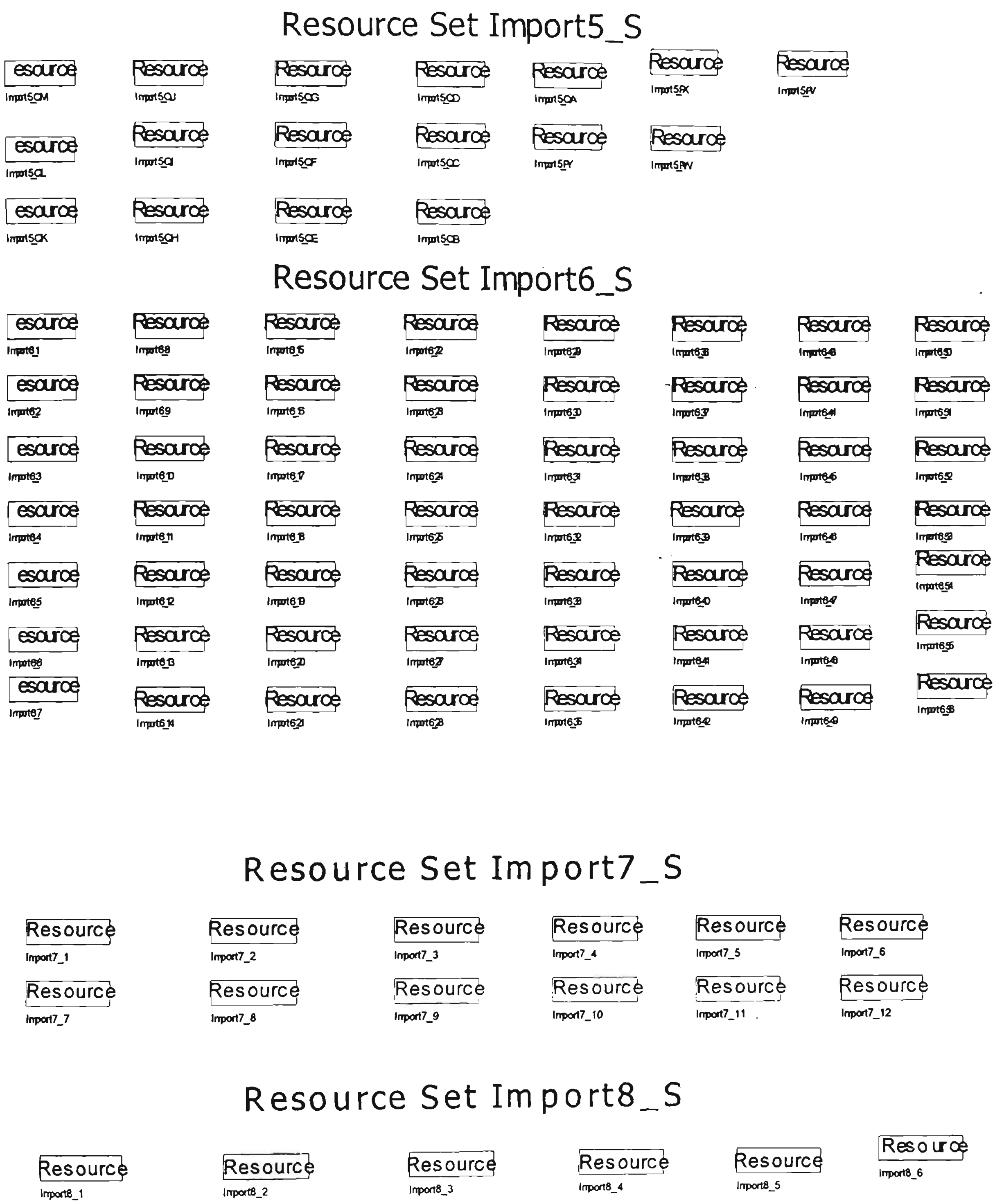


Figure G.10(b). Resource sets for Import container pick-up in yard blocks.

APPENDIX H

ESTIMATES OF EFFECTS OF RESPONSE VARIABLES

H.1. Average container flow time under present POR selection rule

Display H.1 shows the least square estimates of each parameter, the standard error, the t value, and the corresponding p-value. A question of immediate interest is the R-Square value. The R^2 exceeds 0.9804 which indicates that our model explains 98.04% of the total variability. We know the larger the multiple correlation coefficient R^2, the better the fitted equation explains the variation in the data. When the second-order model is fitted to data, its adequacy can be tested by the F-test. The appropriate hypotheses are

$$\begin{aligned} & H_0 : \omega_1 = \omega_2 = \cdots = \omega_g = 0 \\ & H_1 : \omega_j \neq 0 \quad \text{for at least one } j \end{aligned} \qquad [H.1]$$

Rejection of H_0 in Equation H.1 implies that at least one of the regressor variables x_{u1}, $x_{u2} \ldots, x_{ug}$ contributes significantly to the model. If the F value is small to the point that the null hypothesis H_0 can not be rejected, we would have serious doubts about our model. If the F value is large, we are at least assured that the model is feasible. Of course, it does not mean that this particular model is in any way optimal. The F-statistic is basically a comparison of the two variances. The test procedure is to compute the F statistic and to reject the null hypothesis H_0 if the F statistic exceeds $F_{\alpha_n, u, l-u-1}$, the tabulated value of F. The overall F-value associated with the complete second-order model is 44.43. The tabulated 5% value of F for 9 and 8 degrees of freedom is 3.39. The observed value of F exceeds by more than 13 times its 5% significant level. This indicates that it is worthwhile to interpret the fitted surface.

Display H.1. Summary for the scaled coefficients.

```
Call: lm(formula = y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
     Min        1Q   Median      3Q     Max
 -0.4439 -0.08528 0.004545 0.1237 0.3023
```

```
Coefficients:
                 Value Std. Error  t value Pr(>|t|)
(Intercept)     1.7129   0.1431    11.9713   0.0000
         x1    -1.0714   0.0778   -13.7786   0.0000
         x2    -0.5581   0.0778    -7.1777   0.0001
         x3    -0.6454   0.0716    -9.0174   0.0000
    I(x1^2)     0.5315   0.0828     6.4170   0.0002
    I(x2^2)     0.2368   0.0828     2.8582   0.0212
    I(x3^2)     0.2804   0.0600     4.6774   0.0016
      x1:x2     0.2703   0.1012     2.6705   0.0283
      x1:x3     0.4118   0.1012     4.0681   0.0036
      x2:x3    -0.1507   0.1012    -1.4892   0.1748

Residual standard error: 0.2863 on 8 degrees of freedom
Multiple R-Squared: 0.9804
F-statistic: 44.43 on 9 and 8 degrees of freedom, the p-value is 7.04e-
06
```

H.2. Total daily throughput under present POR selection rule

Display H.2 shows the least square estimate of each parameter (coefficients), the standard error, the t statistic and the corresponding p values. We would conclude that the variables arrival time, number of straddles, and straddle speed contribute significantly to the model. The R^2 exceeds 0.9735 which indicates that our model explains 97.35% of the total variability. The overall F value associated with the complete second-order model is 32.61. The tabulated 5% value of F for 9 and 8 degrees of freedom is 3.39. So, the overall regression is significant at $\alpha_n = 0.05$.

Display H.2. Summary for the scaled coefficients.

```
Call: lm(formula = Y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
    Min     1Q Median    3Q   Max
 -45.94 -23.21  1.065 24.37 44.85

Coefficients:
                  Value Std. Error  t value  Pr(>|t|)
(Intercept)   862.4348   21.0374    40.9954    0.0000
         x1  -176.3115   11.4323   -15.4222    0.0000
         x2    32.7049   11.4323     2.8607    0.0211
         x3    46.0000   10.5228     4.3715    0.0024
    I(x1^2)    -1.0798   12.1788    -0.0887    0.9315
    I(x2^2)    -4.6798   12.1788    -0.3843    0.7108
    I(x3^2)   -13.1720    8.8149    -1.4943    0.1735
      x1:x2   -41.2500   14.8815    -2.7719    0.0242
      x1:x3   -60.5000   14.8815    -4.0654    0.0036
      x2:x3   -20.0000   14.8815    -1.3439    0.2158

Residual standard error: 42.09 on 8 degrees of freedom
```

```
Multiple R-Squared: 0.9735
F-statistic: 32.61 on 9 and 8 degrees of freedom, the p-value is
2.312e-05
```

H.3. Average waiting time of jobs in queue for service of straddles under present POR selection rule

The coefficients, the standard error, the t statistic and the corresponding p values of the fitted equation are shown in Display H.3. The predictive model explains only 97.55% (R-Squared: 0.9755) of the total variability in average waiting time of jobs in the queue. We compare the F statistic with the tabulated F (9, 8, 0.95) = 3.39. Since the F-statistic 35.45 is greater than F tabulated, we reject the hypothesis $H_0: \omega_1 = \omega_2 = \omega_3 = \omega_{11} = \omega_{22} = \omega_{33} = \omega_{12} = \omega_{13} = \omega_{23} = 0$. This indicates the fitted equation is significant.

Display H.3. Summary for the scaled coefficients.

```
Call: lm(formula = y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
      Min        1Q     Median       3Q       Max
  -0.6826 -0.2024 0.0008315 0.2446 0.5582

Coefficients:
                 Value Std. Error  t value Pr(>|t|)
(Intercept)    3.1425     0.2338    13.4399   0.0000
         x1   -1.6167     0.1271   -12.7241   0.0000
         x2   -0.8557     0.1271    -6.7345   0.0001
         x3   -1.0299     0.1170    -8.8062   0.0000
    I(x1^2)    0.5992     0.1354     4.4267   0.0022
    I(x2^2)    0.3288     0.1354     2.4293   0.0412
    I(x3^2)    0.3111     0.0980     3.1753   0.0131
      x1:x2    0.2755     0.1654     1.6657   0.1343
      x1:x3    0.3478     0.1654     2.1029   0.0686
      x2:x3   -0.2380     0.1654    -1.4389   0.1881

Residual standard error: 0.4678 on 8 degrees of freedom
Multiple R-Squared: 0.9755
F-statistic: 35.45 on 9 and 8 degrees of freedom, the p-value is 1.68e-
05
```

H.4. Straddle utilisation under POR selection rule

The Display H.4 shows the least square estimate of each parameter, the standard error, the t-statistic, and the corresponding p value of the fitted equation. The predictive model explains only 93.94% of the total variability in straddle utilisation. The overall F value

13.79 is greater than F critical (9, 8, 0.95) = 3.39 and hence we reject the hypothesis $H_0: \omega_1 = \omega_2 = \omega_3 = \omega_{11} = \omega_{22} = \omega_{33} = \omega_{12} = \omega_{13} = \omega_{23} = 0$. The regression is significant, however since the calculated F is only about 4 times the tabulated F value the adequacy of the equation is less than that for the other responses.

Display H.4. Summary for the scaled coefficients.

```
Call: lm(formula = y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
    Min       1Q   Median     3Q    Max
 -1.059 -0.3728 0.005621 0.5031 0.897

Coefficients:
                 Value Std. Error t value Pr(>|t|)
(Intercept)  1.7511  0.4152     4.2173  0.0029
         x1 -1.8815  0.2256    -8.3387  0.0000
         x2 -0.9957  0.2256    -4.4128  0.0022
         x3 -1.0075  0.2077    -4.8508  0.0013
    I(x1^2)  0.4923  0.2404     2.0480  0.0747
    I(x2^2)  0.4668  0.2404     1.9421  0.0881
    I(x3^2)  0.3723  0.1740     2.1398  0.0648
      x1:x2  0.2895  0.2937     0.9855  0.3532
      x1:x3  0.1343  0.2937     0.4573  0.6596
      x2:x3 -0.4201  0.2937    -1.4304  0.1905

Residual standard error: 0.8308 on 8 degrees of freedom
Multiple R-Squared: 0.9394
F-statistic: 13.79 on 9 and 8 degrees of freedom, the p-value is 0.0005686
```

H.5. Average number of jobs in queue under POR selection rule

The Display H.5 shows the coefficients, the standard error, the t value and the corresponding p values. The R-squared value indicates (98.04%) that the model explains most of the variation in the data.

The hypothesis, $H_0: \omega_1 = \omega_2 = \omega_3 = \omega_{11} = \omega_{22} = \omega_{33} = \omega_{12} = \omega_{13} = \omega_{23} = 0$ is tested with $\alpha_n = 0.05$ by comparing the computed $F(9, 8)$ for $\alpha_n = 0.05$. The tabulated 5% value of F for 9 and 8 degrees of freedom is 3.39. Since 44.56 is greater than 3.39, we reject the hypothesis $H_0: \omega_1 = \omega_2 = \omega_3 = \omega_{11} = \omega_{22} = \omega_{33} = \omega_{12} = \omega_{13} = \omega_{23} = 0$. The observed value of F exceeds by more than 11 times its 5% significant level. The overall regression is significant and so are all individual coefficients.

Display H.5. Summary for the scaled coefficients.

```
Call: lm(formula = y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
     Min      1Q   Median     3Q    Max
 -0.7378 -0.225 0.004482 0.2795 0.6072

Coefficients:
                Value Std. Error  t value Pr(>|t|)
(Intercept)   -0.3876   0.2583    -1.5007   0.1718
         x1   -2.1565   0.1403   -15.3656   0.0000
         x2   -0.9637   0.1403    -6.8665   0.0001
         x3   -1.2228   0.1292    -9.4659   0.0000
    I(x1^2)    0.6433   0.1495     4.3029   0.0026
    I(x2^2)    0.3487   0.1495     2.3321   0.0480
    I(x3^2)    0.2801   0.1082     2.5882   0.0322
      x1:x2    0.2570   0.1827     1.4069   0.1971
      x1:x3    0.2503   0.1827     1.3701   0.2079
      x2:x3   -0.2802   0.1827    -1.5340   0.1636

Residual standard error: 0.5167 on 8 degrees of freedom
Multiple R-Squared: 0.9804
F-statistic: 44.56 on 9 and 8 degrees of freedom, the p-value is
6.963e-06
```

H.6. Average container flow time under proposed SDS selection rule

The Display H.6 shows the coefficients, the standard error, the t statistic and the corresponding p value of the fitted equation. The R-squared exceeds 0.9829 which indicates that our model explains more than 98.29% of the total variability. The overall F value associated with the complete second order model is 51.16. The tabulated 5% value of F for 9 and 8 degrees of freedom is 3.39. The observed value of F exceeds by more than 15 times its 5% significant level. This indicates it is worthwhile to interpret the fitted surface.

Display H.6. Summary for the scaled coefficients.

```
Call: lm(formula = y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
     Min       1Q   Median     3Q    Max
 -0.4092 -0.07647 0.00763 0.1263 0.3042

Coefficients:
                Value Std. Error  t value Pr(>|t|)
(Intercept)    1.7156   0.1325    12.9502   0.0000
         x1   -1.0661   0.0720   -14.8087   0.0000
         x2   -0.5539   0.0720    -7.6934   0.0001
         x3   -0.6463   0.0663    -9.7528   0.0000
    I(x1^2)    0.5380   0.0767     7.0157   0.0001
```

```
 I(x2^2)     0.2301    0.0767     2.9999   0.0171
 I(x3^2)     0.2761    0.0555     4.9744   0.0011
   x1:x2     0.2499    0.0937     2.6666   0.0285
   x1:x3     0.3955    0.0937     4.2202   0.0029
   x2:x3    -0.1241    0.0937    -1.3240   0.2221

Residual standard error: 0.2651 on 8 degrees of freedom
Multiple R-Squared: 0.9829
F-statistic: 51.16 on 9 and 8 degrees of freedom, the p-value is
4.074e-06
```

H.7. Total throughput under SDS selection rule

The Display H.7 shows the *R*-squared value explains more than 97.37% of the total variability in the data. The *F* value 32.91 is greater than the *F* critical value (9, 8, 0.95) = 3.39. This indicates the fitted equation is significant.

Display H.7. Summary for the scaled coefficients.

```
Call: lm(formula = Y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
    Min     1Q Median    3Q   Max
 -46.09 -19.21  0.385 20.83 48.69

Coefficients:
                Value Std. Error   t value  Pr(>|t|)
(Intercept)  861.6150    20.8804   41.2643    0.0000
         x1 -174.8852    11.3470  -15.4125    0.0000
         x2   33.1967    11.3470    2.9256    0.0191
         x3   46.2500    10.4443    4.4282    0.0022
    I(x1^2)   -0.3074    12.0880   -0.0254    0.9803
    I(x2^2)   -2.4674    12.0880   -0.2041    0.8434
    I(x3^2)  -12.5911     8.7492   -1.4391    0.1881
      x1:x2  -45.0000    14.7705   -3.0466    0.0159
      x1:x3  -62.2500    14.7705   -4.2145    0.0029
      x2:x3  -16.2500    14.7705   -1.1002    0.3033

Residual standard error: 41.78 on 8 degrees of freedom
Multiple R-Squared: 0.9737
F-statistic: 32.91 on 9 and 8 degrees of freedom, the p-value is
2.233e-05
```

H.8. Average waiting time of jobs in queue under SDS selection rule

The Display H.8 shows the model explains only 97.7 percent (*R*-squared: 0.977) of the total variability in our data. The *F* critical value 37.73 is more than *F*-critical value (9, 8, 0.95) = 3.39 which indicates the model is significant.

Display H.8. Summary for the scaled coefficients.

```
Call: lm(formula = y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
     Min       1Q  Median     3Q    Max
 -0.6397 -0.2051 0.01311 0.2492 0.5817

Coefficients:
                Value Std. Error  t value Pr(>|t|)
(Intercept)    3.1458    0.2259   13.9257   0.0000
         x1   -1.6093    0.1228  -13.1091   0.0000
         x2   -0.8589    0.1228   -6.9967   0.0001
         x3   -1.0349    0.1130   -9.1586   0.0000
    I(x1^2)    0.6174    0.1308  - 4.7213   0.0015
    I(x2^2)    0.3274    0.1308    2.5038   0.0367
    I(x3^2)    0.3048    0.0947    3.2202   0.0122
      x1:x2    0.2398    0.1598    1.5009   0.1718
      x1:x3    0.3019    0.1598    1.8895   0.0955
      x2:x3   -0.1992    0.1598   -1.2469   0.2477

Residual standard error: 0.452 on 8 degrees of freedom
Multiple R-Squared: 0.977
F-statistic: 37.73 on 9 and 8 degrees of freedom, the p-value is
1.322e-05
```

H.9. Straddle utilisation under SDS selection rule

The Display H.9 shows the *R* squared exceeds 0.7547 which indicates that our model explains only 75.47% of the total variability. The fitted model is statistically significant. However 25% of the variability remains unexplained. The overall *F* value associated with the complete second order model is 16.82. The tabled 5% value of *F* for 9 and 8 degrees of freedom is 3.39. The observed value of *F* exceeds by around 5 times its 5% significant level. This indicates it is worthwhile to interpret the fitted surface, although the adequacy is less than that for other responses.

Display H.9. Summary for the scaled coefficients.

```
Call: lm(formula = y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
     Min      1Q   Median     3Q    Max
 -0.9369 -0.3912 0.002732 0.5012 0.8379

Coefficients:
               Value Std. Error t value Pr(>|t|)
(Intercept)  1.7528   0.3772     4.6466  0.0017
         x1 -1.8902   0.2050    -9.2209  0.0000
         x2 -1.0111   0.2050    -4.9324  0.0011
         x3 -1.0072   0.1887    -5.3378  0.0007
    I(x1^2)  0.5133   0.2184     2.3503  0.0467
```

```
  I(x2^2)  0.4990  0.2184     2.2849  0.0517
  I(x3^2)  0.3483  0.1581     2.2037  0.0587
    x1:x2  0.2640  0.2668     0.9893  0.3515
    x1:x3  0.1679  0.2668     0.6293  0.5467
    x2:x3 -0.3531  0.2668    -1.3232  0.2223

Residual standard error: 0.7547 on 8 degrees of freedom
Multiple R-Squared: 0.9498
F-statistic: 16.82 on 9 and 8 degrees of freedom, the p-value is
0.0002767
```

H.10. Average number of jobs in queue under SDS selection rule

The Display H.10 shows the R-squared value exceeds 0.9326 which indicates that our model explains 93.26% of the total variability. The fitted model is statistically significant. Since F (9, 8, 0.95) = 3.39, the overall regression is statistically significant i.e., 12.3 > 3.39. Again although the model is adequate it is less than for most of the other responses.

Display H.10. Summary for the scaled coefficients.

```
Call: lm(formula = y ~ (x1 + x2 + x3)^2 + x1^2 + x2^2 + x3^2)
Residuals:
    Min       1Q  Median      3Q  Max
 -1.435 -0.3937 0.01406 0.4235 1.19

Coefficients:
               Value Std. Error t value Pr(>|t|)
(Intercept) -0.3899  0.4502    -0.8661  0.4116
         x1 -2.0096  0.2446    -8.2151  0.0000
         x2 -0.8069  0.2446    -3.2986  0.0109
         x3 -1.1071  0.2252    -4.9167  0.0012
    I(x1^2)  0.5782  0.2606     2.2186  0.0573
    I(x2^2)  0.2990  0.2606     1.1473  0.2844
    I(x3^2)  0.2443  0.1886     1.2952  0.2314
      x1:x2 -0.0634  0.3184    -0.1992  0.8471
      x1:x3 -0.0661  0.3184    -0.2075  0.8408
      x2:x3 -0.4929  0.3184    -1.5478  0.1603

Residual standard error: 0.9007 on 8 degrees of freedom
Multiple R-Squared: 0.9326
F-statistic: 12.3 on 9 and 8 degrees of freedom, the p-value is
0.0008537
```

APPENDIX I

Questionnaire

VICTORIA UNIVERSITY

Part 1. Management of Information Systems

Note: Please answer only the questions that are important or relevant to you.

A. General information

1) Do you have a computer integrated terminal operations system (CITOS) to support your container operation?

☐ Yes ☐ No

2) If yes, which of the following modern information system and information technology are you using for container terminal operation?

☐ Electronic data interchange (EDI).
☐ Automatic Equipment Identification (AEI).
☐ Global Positioning System (GPS)
☐ Position determination system (PDS)
☐ None of above
☐ Other (Specify) ________________

3) Is your terminal interacting in its daily activities of container operations with the following agents? (Please tick more one or more of the following boxes)

☐ Other container terminal operator
☐ Shipping companies
☐ Custom brokers
☐ Port authorities
☐ Cargo insurers
☐ Quarantine
☐ Trucking Companies
☐ Freight forwarders
☐ Importers
☐ Exporters
☐ Trading banks
☐ Rail freight offices
☐ Shipping agencies
☐ Container depots

4) Please indicate which of the following information your management needs from your agencies related to the import of containers? (Please tick more than one box.)

☐ Notifies consignees of arrival notice (between shipping companies and brokers)
☐ Freight release information (between shipping companies and terminal operator)

☐ Container available information (between transport companies and terminal operator)
☐ Information about container status (between brokers and trucking companies)
☐ Clearance information (between brokers and port authorities)
☐ Forward bill of lading (BOL) or delivering order between brokers and transport companies.
☐ Container release information between regulating agencies and management
☐ Other information (Specify) ______________

5) Please indicate which of the following information your management need from your agencies related to the export of containers?

☐ Forward dock receipt between terminal operator and shipping companies
☐ Issues ocean bill of lading or similar documents of title between shipping companies and shippers
☐ Send bill of lading between shippers and forwarder
☐ Sends original dock receipt between transport companies and terminal operator
☐ Request for special equipment, if needed between transport carrier and forwarder
☐ Export permits between shippers and port authorities
☐ Secure interchange agreement between shipping companies and transport companies
☐ Other (specify) _________________

B. Information about container location system

1) Do you have difficulty of locating container in the storage yard?

☐ Yes
☐ No, why? ____________________

2) If yes, Please indicate the level of difficulty in locating containers in the storage yard?

☐ Small ☐ Moderate
☐ High ☐ None

3) Which of following are you using for updating the location of containers?

☐ Daily ☐ Before each ship's arrival
☐ Every shift operation ☐ Real time updating system
☐ Other (Specify) _________________

4) What is the total number of containers handled in each month?

- ☐ Less than 5000 TEUs
- ☐ Between 5000 and 10,000 TEUs
- ☐ Between 10,000 and 20,000 TEUs
- ☐ Between 20,000 and 30,000 TEUs
- ☐ Above 30,000 TEUs

5) How do you perform the task of container locations in the yard?

- ☐ Use clerks to identify containers
- ☐ Using magnetic strip cards
- ☐ Radio frequency in conjunction with clerks
- ☐ Position determination system (PDS), using radio data transmission system
- ☐ Other (Specify) ______________________

6) If you are using clerks (traditional approach) how many person-hours/month do they need to identify the containers per every 1000 TEUs?

- ☐ 0 to 20 person-hrs/months
- ☐ 21 to 50 person-hrs/months
- ☐ 51 to 100 person-hrs/months
- ☐ 101 to 150 person-hrs/months
- ☐ Above 151 person-hrs/months
- ☐ Not calculated

7) What technology do you use to transmit container location data to storage in the container terminal?

- ☐ On line system
- ☐ Radio frequency devices (data transfer technology)
- ☐ Sent information manually
- ☐ Manual and radio frequency
- ☐ Planning to implement such system
- ☐ Other (Specify) __________________

8) Are you using container location information in computers?

☐ Yes ☐ No ☐ Other (Specify) ______________

9) What are you using the container location information for?

☐ For yard plan
☐ For statistical purposes (performance measures)
☐ Book keeping
☐ Other (specify) ________________

10) How do you track the movements of containers within the stacking area?

☐ Position determination system (PDS) in conjunction with radio data transmission technology
☐ PDS in conjunction with cargo handling real time system
☐ Other (Specify) ________________

C. Information about the gate system

1) How do you identify the trucks carrying containers at gate to facilitate faster clearance?

☐ Closed circuit television (CCTV)
☐ Transponder reader
☐ Container number recognition system (CNRS)
☐ Tachograph
☐ Other (Specify) ________________

2) How do you book the time-slot for road vehicles?

☐ Booking through on-line access to the system
☐ Booking by telephone
☐ Booking by facsimile
☐ Other (Specify) ________________

3) How do you identify the truck drivers?

☐ Booth attendants or clerks
☐ Magnetic strip cards (special cards)
☐ Bar coded cards
☐ Not verified
☐ Other (specify) ________________

4) How do you identify the trucks in the terminal?

☐ Transponders
☐ Close circuit TV cameras
☐ Booth attendants
☐ Tickets (a system based on the use of magnetic cards)
☐ Other (Specify)___________________________

D. Information about the use of electronic data interchange (EDI)

1.) Are you using electronic data interchange in the container terminal?

☐ Yes ☐ No

2.) If yes, please indicate the level of EDI involved in export and import process of containers?

☐ Low ☐ Moderate ☐ Intense

E. Information about container-status inquiry system

1.) Do you have a container-status inquiry system?

☐ Yes ☐ No

2.) If yes, what type of system you have?

☐ Touch tone telephone access to your system
☐ On-line access to your system
☐ Planning for implementation of container-status inquiry system
☐ At present do not have
☐ Project stage
☐ Other (Specify) ________________

3.) If a system is available for on-line access to the agents such as shipping companies, government agencies, brokers, railroads and trucking companies how many hours of access available to them?

☐ 7.00 AM to 2.30 PM
☐ 6.00 AM to 11 PM
☐ 24 hours
☐ 2.30 PM to 10 PM
☐ 7 days a week
☐ Other (Specify) ___________

4.) Who are the end users of the on-line access to system?

- ☐ Shipping companies
- ☐ Rail road agents
- ☐ Transport companies
- ☐ Government agencies
- ☐ Brokers
- ☐ Other (Specify) ______________

5) What is the level of use of information about container-status inquiry system?

- ☐ Intense
- ☐ Moderate
- ☐ Low

F. Information about other interactions

1.) How do you release freight?

- ☐ By EDI
- ☐ Release sent manually
- ☐ By fax
- ☐ Combination of EDI and fax
- ☐ Courier and mail
- ☐ Do not know
- ☐ Other (Specify) ______________

2.) If the transport companies are not using EDI for transactions linked to brokers what other methods are you using for sending bills of lading?

- ☐ Fax
- ☐ Mail and courier service
- ☐ By messenger
- ☐ Other (Specify) ______________

3.) How do you verify the credit of transport carrier?

- ☐ Manually
- ☐ Do not verify credit
- ☐ Electronically
- ☐ Not concerned

4.) What methods are used to pay demurrage?

- ☐ By mail
- ☐ Electronic and personally
- ☐ In person
- ☐ Not charged

G. About the future

1) Do you believe that information technology help you to update container location in container terminal?

☐ Yes ☐ No ☐ Conditional

2) Do you think you will use radio frequency tags?

☐ Yes ☐ No ☐ Conditional

3) Do you think that benefits from standardisation would lead to higher productivity?

☐ Yes ☐ No ☐ Conditional

Part 2. Container handling equipment and automation

H. Container handling equipment

1) Are your quay cranes equipped with a crane management system which provides operational, maintenance, fault diagnostics, and trouble-shooting facilities on board the cranes?

☐ Yes
☐ No
☐ Planning to implement in future
☐ Other (Specify) ______________________________

2) Are the yard cranes using?

☐ Out dated technology ☐ Modern technology

3) If modern technology, what type of system does your crane have

☐ Digital drive system
☐ Crane management system
☐ Automatic position indicating system
☐ Automatic travel control system to facilitate semi-automatic mode of operation
☐ Other (specify) ________________________

I. Equipment automation

1) Do you think automation of equipment changes productivity over complex shifts?

☐ Yes ☐ No ☐ Conditional

2) Which of the following ways you would prefer your equipment automation?

☐ Electronic positioning in container terminal
☐ Automatic steering for rubber-tyred gantry cranes
☐ Phased introduction of automated handling system so as to minimise operating costs
☐ Improve by any reasonable means the standard of service provided to shipping lines and to their customers
☐ Other (Specify) ____________________

3) Are you using computers for storage planning?

☐ Yes
☐ No
☐ Planning to implement in future
☐ Other (Specify) ____________________

4) Are you using storage yard operation and planning by computer?

☐ Yes
☐ No
☐ Planning to implement
☐ Other (Specify) ____________________

Part 3. Performance measures

1.) Which of the following delays do you consider for ship exchange delays (non-operational delays) whilst vessels are at berth?

☐ Delay in boarding ship
☐ Completion-to-sailing time
☐ No labour rostered
☐ Port-wide industrial dispute
☐ Other (specify)____________________

2.) Which of the following delays do you consider for ship working delays (operational delays) whilst vessels are alongside the berth?

- ☐ Quay crane boom up/down for other vessels
- ☐ Award shift break
- ☐ Delay caused by the ship
- ☐ Smoke/meal break
- ☐ Handling break-bulk cargo
- ☐ Ramp work only (for RO RO ship)
- ☐ Rostered labour with held
- ☐ Handling ship's hatch lids
- ☐ Delay caused by need for cage
- ☐ Conlocking and lashing work
- ☐ Weather related delays
- ☐ Other (specify)____________________

3) Which of the following delays do you consider as crane delays when a crane is exchanging containers?

- ☐ Delay caused by the ship
- ☐ Crane boom up/down for other vessels
- ☐ Smoke/meal break
- ☐ Handling break-bulk cargo
- ☐ Long travel moves of cranes
- ☐ Crane break down
- ☐ Weather related delays
- ☐ Other (specify) ____________________

Part 4. Contact details (Optional)

1) Would you like to get a copy of the findings of this survey report?

☐ Yes ☐ No

2) If yes, please give postal address or email

Contact name:________________________________ Position: ________________

Container terminal name: ____

Address: ________________________________ Suburb: ________________

State: ____________ Country ______________ Postcode: ________________

Phone: _________________________________ Fax: __________________

E-mail: ______________________________

THANK YOU FOR YOUR ASSISTANCE.
Now please return your completed questionnaire before 15th May 1999 in the envelope provided.