AN OPERATIONAL SYSTEM MODEL FOR RAW MATERIAL FLOW IN THE SUGARCANE MILL YARD OF MUMIAS SUGAR COMPANY

By

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A Thesis Submitted to The University of Nairobi in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE IN AGRICULTURAL ENGINEERING Faculty of Engineering 1993
DECLARATION

I declare that this is my original work and has not been submitted for a degree in any other University.

Date 10/02/1994

Marenya, M. O.

This thesis has been submitted for examination with our approval as University Supervisors

Date 10/2/94

Dr. P. G. Kaumbutho

Date 10th February 1994

Mr. D. A. Mutuli
DEDICATION

This study is dedicated to my Parents, Brothers, Sisters and my wife, Betty:

In appreciation of the roles they have played and continue to play in my life.
ACKNOWLEDGEMENTS

First, I give thanks to God Almighty for making all that was undertaken in this study possible.

I acknowledge the management of Mumias Sugar Company for offering funds and facilities for this project. My thanks go to Mr. J. Matete (Agricultural Services Manager, MSC) and Mr. F. T. Wabuke (Special Projects and Investigation Manager, MSC) in whose departments I was attached for accepting me as part of their staff during my stay in Mumias.

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ABSTRACT

AN OPERATIONAL SYSTEM MODEL FOR RAW MATERIAL FLOW IN THE SUGARCANE MILL YARD OF MUMIAS SUGAR COMPANY

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A study was conducted at Mumias Sugar Company to identify the parameters that determine the flow rate of cane into and out of the factory’s Cane Yard between November, 1991 and May, 1992. The study utilized current as well as previously recorded (historical) data where available.

Statistical analysis was carried out on all the data that was gathered. From the analysis, curves were fitted using the chi-square goodness of fit test. Equations that described the service times of all the unloading equipment in the yard were derived.

A computer simulation model of the Cane Yard operations was developed. The model developed was capable of simulating the operations of the factory’s Cane Yard. Cane inflow rates, milling rates, stockpile build-up in the yard and the average waiting times of all the trailer types were derived from the model. Simulated and actual Cane Yard parameters were compared.

The model was used to determine the possibility of Mumias Sugar Company operating only two daily transportation shifts of 8 hours, while satisfying the daily mill requirements. This was found possible by increasing the hourly delivery rates of basket type trailers so that the majority of the cane hauled into the yard by bundled cane trailers during the first 16 hours of operation is stockpiled. However, the average waiting time for basket type trailers may become the limiting parameter, particularly when there is a mill breakdown.
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LIST OF ABBREVIATIONS

Terms Used in the Mathematical Model and Computer Simulation Program:

Environmental factors

1. PWF - Power factor, equal to one (1) if there is power.

2. RNF - Rain factor, equal to one (1) if there is no rain. If factor is equal to one then the conditions are conducive for unloading.

Cane Yard unloading equipment

1. HYDA - Hydro-Loader A. Unloads the basket units loose cane onto Mill A Feed table for crashing.

2. HYDB - Hydro-Loader B. Unloads the basket units loose cane onto Mill B Feed table for crushing.

3. GCS - Gantry cranes. Unloads the non-Self tipping trailers to a stockpile or directly on a Mill Feed Table. At times are fitted with grabs to load Mill Table with cane from the stockpile.

4. HYDC - Hydro-Loader C, used to unload basket units when the queue behind HYDA and HYDB become too long. The cane unloaded by this equipment is later fed to mill by the Front-End Wheel loader.

5. CAM ECO - A Front-End-Wheel loader used in feeding Mill A with cane from the Self-tipping trailer stock and feeding Mill B table with cane from the stockpile of HYDC and occasionally feeding the mills with cane from the stock piling area.

Number of units

1. NBA - Simulated (generated) number of basket type units for Mill A during any chosen hour.

2. ONBA - Original number of basket type units waiting to be unloaded to Mill A Feed table. This is the sum of the simulated number of basket type unit for Mill A plus any surplus number of basket units from the previous hour.

3. RNBA - Remaining number of basket units after an hour has elapsed. These are carried over to the next hour and NBA generated added onto give the ONBA for HYDA during the next hour.

4. NBB - Simulated (generated) number of basket type units for Mill B during any chosen hour.
5. ONBB - Original number of basket type units for Mill B Feed table. This is the sum of the simulated number of basket type units for Mill B plus any surplus number of basket units from the previous hour.

6. RNBB - Remaining number of basket units after an hour has elapsed. These are carried over to the next hour and NBB generated added onto give the ONBB for HYDB during the next hour.

7. NBC - Simulated (generated) number of basket type units for HYDC during any given hour.

8. ONBC - Original number of basket type units waiting to be unloaded by HYDC. This is the sum of the simulated number of basket type units for HYDC plus any surplus number of basket units from the previous hour.

9. RNBC - Remaining number of basket units after an hour has elapsed. These are carried over to the next hour and NBC generated added onto give the ONBC for HYDC during the next hour.

10. NBD - Simulated number of bundled unit trailers. This is later broken down to give the bundle units to be unloaded by the Gantry cranes and the Self-tipping units.

11. NBDGC - Remaining number of bundled units that arrive at the Cane Yard for unloading by the Gantry cranes. NBDGC is a fraction of NBD.

12. ONBDGC - Original number of bundle units waiting to be unloaded by the Gantry cranes at the beginning of any hour.

13. RNBDGC - Remaining number of bundle units at the end of an hour. These are added onto NBDGC to give the ONBDGC for the next hour.

14. NBDST - Number of Self-tipping trailers that arrive at the Cane Yard for unloading. These units unload their cane at a chosen area, separate from bundled units unloaded by the gantry cranes.

15. ONBDST - Original number of Self-tipping trailers at the beginning of every hour.

16. RNBDST - Remaining number of Self-tipping trailers (i.e those that did not unload during the hour since they joined the queue) after any hour. These are added onto NBDST at the beginning hour to give ONBDST.

Mean arrival rates of units

1. ABK - Mean hourly arrival rates of Loose cane (basket) units at HYDA

2. BBK - Mean hourly arrival rates of Loose cane units at HYDB.
3. **ABBD** - Mean hourly arrival rate of bundle cane units. Comprise both Self-tipping and Ordinary bundle trailer units.

**Program and procedures constants**

1. **MHYDA** - Mean hourly unloading rate of HYDA.
2. **MHYDB** - Mean unloading rate of HYDB
3. **MGCU** - Mean hourly unloading rate of a Gantry crane.
4. **MSTU** - Mean hourly unloading rate of Self-tipping trailers.
5. **SizeRU** - Maximum number of random numbers generated for an hour's Cane Yard simulation.
6. **PLBK** - Payload of a Single Loose cane unit (taken as equal to 6.5 tonnes).
7. **PLST** - Payload of a Single Bundle cane unit (taken as equal to 6.0 tonnes).
8. **PLGC** - Payload of a Single Bundled cane unit (taken as equal to 6.0 tonnes)
9. **TVOLA** - Total (Maximum) available stockpiling tonnage under the Gantry cranes unloading area.

**Arrays and Files for data storage**

1. **List** - An array that stores the random numbers generated by the RNG procedure. The array cells are accessed during program execution to obtain the random numbers required by the various program procedures.
2. **Mill** - An array that stores the milling rate values in a file. The cells are accessed to give the sampled milling rate for any hour.
3. **upa** - An array that stores the upper limit random numbers for mill A in file g.
4. **upb** - An array that stores the upper limit random numbers for mill B.
5. **H** - An array that stores the hour of operation. It is accessed to obtain the hour component in the file g.
6. **LCA** - An array that contains the mean hourly arrival rates for Loose cane arrival in file g. It is accessed to obtain ABK for the hour H.
7. **LCR** - An array that contains the mean hourly rate for Loose cane arrival in file g. It is accessed to obtain BBK for the hour H.
8. BC - An array that contains the mean hourly arrival rate for bundle cane arrival in file g. It is accessed to obtain ABBD for hour h.

9. GC - An array that contains number of working Gantry cranes (those doing the unloading job) in file h.

10. URNDGC - An array that contains the upper limit random numbers for the number of working Gantry cranes.

Stock levels

1. STSTOCK - Self-tipping stock level at the end of an hour. This is the quantity of the Self-tipping stock that is left after Mill A has been satisfied.

2. GCSTOCK - Stock level under the Gantry cranes. This is the quantity of cane remaining in the area under the Gantry cranes after both Mills A and B have been fed.

3. RSTOCK - Average quantity of cane required to satisfy the mill till 6.00 a.m in the morning of the following day. A product of the average milling rate of both mills and the remaining hours of operation to complete a day's run.

4. TSTOCK - Sum of STSTOCK and GCSTOCK. Determines when to park all the cane trailers with cane outside the Cane Yard until the following day.

Terms used for milling rates

1. MillA - The remaining Mill A requirement during an hours operation.

2. MillB - The remaining Mill B requirement during an hours operation.

3. MAI - Sampled (simulated) Mill A requirement at the beginning of an hour. Equal to MillA if there's no cane or power to feed mill A, or there are problems which make it impossible for MillA to be fed.

4. MBI - Sampled (simulated) Mill B requirement at the beginning of an hour. Equal to MillB if there's no cane or power to feed Mill B, or there are problems which makes it impossible for Mill B to be fed.

5. AMill - The average milling rate for the whole factory since the milling started for a day's operation. Used in determining the RSTOCK at the end of an hour's operation.


8. BC - An array that contains the mean hourly arrival rate for bundle cane arrival in file g. It is accessed to obtain ABBD for hour h.

9. GC - An array that contains number of working Gantry cranes (those doing the unloading job) in file h.

10. URNDGC - An array that contains the upper limit random numbers for the number of working Gantry cranes.

Stock levels

1. STSTOCK - Self-tipping stock level at the end of an hour. This is the quantity of the Self-tipping stock that is left after Mill A has been satisfied.

2. GCSTOCK - Stock level under the Gantry cranes. This is the quantity of cane remaining in the area under the Gantry cranes after both Mills A and B have been fed.

3. RSTOCK - Average quantity of cane required to satisfy the mill till 6.00 a.m in the morning of the following day. A product of the average milling rate of both mills and the remaining hours of operation to complete a day’s run.

4. TSTOCK - Sum of STSTOCK and GCSTOCK. Determines when to park all the cane trailers with cane outside the Cane Yard until the following day.

Terms used for milling rates

1. MillA - The remaining Mill A requirement during an hours operation.

2. MillB - The remaining Mill B requirement during an hours operation.

3. MAI - Sampled (simulated) Mill A requirement at the beginning of an hour. Equal to MillA if there’s no cane or power to feed mill A, or there are problems which make it impossible for Mill A to be fed.

4. MBI - Sampled (simulated) Mill B requirement at the beginning of an hour. Equal to MillB if there’s no cane or power to feed Mill B, or there are problems which makes it impossible for Mill B to be fed.

5. AMill - The average milling rate for the whole factory since the milling started for a day’s operation. Used in determining the RSTOCK at the end of an hour’s operation.


Time notations.

(a) Inter-Arrivals Times for Various Truck Types.

1. TABK - Sampled inter-arrival time of Loose cane (basket) units through weighbridge A.
2. TBBK - Sampled inter-arrival times of loose cane through weighbridge B.
3. TBD - Sampled inter-arrival times of bundle cane units through both weighbridges.

(b) Sum of the Inter-Arrival Times.

1. TATBK - Summation of TABK. Used to determine when to stop sampling arrivals through WBA during any chosen hour.
2. TBTBK - Summation of TABK. Used to determine when to stop sampling arrivals through WBB during any chosen hour.
3. TTBD - Summation of TBD. Used to determine when to stop sampling arrival of bundle cane units.

(c) Unloading (service) times.

1. THYDA - Time taken by the Hydro-loader A to unload one unit of Loose cane trailer.
2. TOTHYDA - Summation of THYDA. This should be less than or equal to 1 hour. Determines when to stop an hour’s unloading operation by HYDA.
3. THYDB - Time taken by the Hydro-loader B to unload one unit of Loose cane trailers.
4. TOTHYDB - Summation of THYDB. This should be less than or equal to 1 hour. Determines when to stop an hour’s unloading operation by HYDB.
5. TST - Time taken by a Self-tipping trailer to unload itself.
6. TOTST - Summation of TST. Should be less than or equal to 1 hour. Determines when to stop an hour’s unloading operation for the Self-tipping trailers.
7. TGC - Time taken by a Gantry crane to unload one unit of bundled cane.
8. TOTGC - Summation of TGC. This is updated up to a total duration of one hour. After which a channel’s unloading operation is stopped and another channel taken until the number of operating Gantry cranes for that hour are reduced to zero or the units to be unloaded by the Gantry crane equal zero or TVOLA is attained (i.e the area under the Gantry cranes is all used up).
(d) Waiting time of cane loaded trailers.

1. WTI  - Contribution to the hourly average waiting time for Self-tipping trailers that are unloaded within the hour.

2. WTO  - Contribution to the average waiting time of the Self-tipping trailers by the units which are unloaded at the end of the hour.

3. WST  - Average hourly waiting of the Self-tipping trailers returned by the simulation program during execution.

4. WBI  - Contribution to hourly average waiting time of the loose cane (basket type) trailers unloaded within the hour by HYDB.

5. WBO  - Contribution to the average waiting time of the loose cane trailers unloaded by HYDB that are still in queue by the end of the hour.

6. WBB  - Average hourly waiting time of the loose cane trailers unloaded by HYDB. A sum of WBI and WBO.

7. WBA  - Average hourly waiting time of the loose cane trailers unloaded by HYDA. A sum of WAI and WAO.

8. WAI  - Contribution to hourly average waiting time of Loose cane trailers unloaded within the hour by HYDA.

9. WAO  - Contribution to the average waiting time of the Loose cane trailers unloaded by HYDB that are still in queue by the end of the hour.

10. WGI - Contribution to hourly average waiting time of the Gantry crane unloaded bundle cane trailers that are unloaded within the hour.

11. WI   - A channel's contribution to the average hourly waiting time for the Gantry crane unloaded bundle units unloaded within the hour. The sum gives WGI for a given hour.

12. WGO - Contribution to the hourly average waiting time of the Gantry crane unloaded units that are not unloaded by the end of the hour.

13. WGC - Average hourly waiting time of the Gantry crane unloaded bundled cane units.
CHAPTER 1: INTRODUCTION

The importance of the sugar industry in Kenya is best explained by the three objectives that led to the industry's development after independence. These are:-

1. To realize self sufficiency in sugar production with moderate surplus for export.
2. To create a foreign exchange saving industry by not importing large quantities of sugar.
3. To provide employment in the rural areas and as a source of income to farmers.

Currently sugar production is confined to Western and Nyanza provinces in Kenya and in total there are six operating sugar factories. In 1989, only one factory in each of the two provinces were operating at a profit. Mumias Sugar company (MSC) in Western province had a large profit margin while Chemelil Sugar company in Nyanza (Province) sugar belt had a low profit margin. The negative profit margins observed in the other four operating sugar factories should be of a major concern to all Kenyans.

As stated by Awilly (1991), there has never been any industrial research to improve on Kenya sugar industry performances. With declining sugar industry's performance, it is likely that Kenya's sugar production will continue to fall as the demand for sugar increases. Currently there is fear that Kenya might remain a net importer of sugar due to the sugar industry's declining performance, while the demand for sugar is increasing partly due to population growth and partly due to growth in per capita income (Awilly, 1990).

In any manufacturing industry, the objective is to minimize production costs of the goods by utilizing the labour, machinery and other equipment efficiently. In sugar processing the flow of input and output materials is of great importance as it determines factory processing efficiency. Material flow of a sugar factory can be improved if the bottlenecks that affect the
materials flow rates can be identified and eliminated. An inexpensive way of doing this is to model the sugar cane processing system such that the effects of input variables on the output are predictable.

Computer modelling is a technique that is used to model many production systems as an efficient and cheap way of analyzing the systems performance so as to identify the bottlenecks and find ways of reducing or completely eliminating them. Computer modelling has the advantage of speed and lends itself to a real life situation. This technique also allows for modifications to be incorporated as the modelling process progresses. The approach that has been employed by many system scientists in modelling real life (i.e complex) systems is to divide the whole into sub-systems that are manageable and model one at a time (Kobayashi, 1978). Modelling approaches that have been widely used are analytical, simulation, and empirical. Among these, simulation modelling is the most widely used as it has the ability of describing the dynamic behaviour of a system (Kobayashi, 1978).

The Kenyan Sugar industry in general has attributed inefficiencies in flow of materials within the sugar processing system which need a close analytical study if they are to be understood and consequently eradicated. A study of this type would help define and locate sub-system and overall system efficiencies and bottlenecks. A knowledge of the nature of the bottlenecks and their locations would help the engineering and administrative personnel propose modifications in operations and components that would lead to improved system performance. At the abstract level more sugar would be produced without major system changes. At the least a better understood system would result.

Mumias Sugar Company (MSC) is a sugar manufacturing establishment that has been operational since 1973. In its first year of operation, the factory produced only 20,892 tonnes of sugar. Sugar production by MSC rose from then to a maximum of over 210,000 tonnes by 1988. This is more than 50% of all the sugar manufactured locally (MSC annual report, 1988/89).
Mumias Sugar Company controls a sugar cane growing zone of about 37,840 hectares of which 3,380 hectares are within the company's Nucleus estate and 34,458 hectares are under the Mumias Outgrowers Company (Owende, 1990). This growing area is capable of ensuring that the factory's annual cane requirement is met.

MSC factory receives the bulk of its cane from the nucleus estate and the outgrowers' farms. Some cane is at times received from the non-contracted farmers and the Nzoia sugar company's sugar zone. The last two do not supply a significant amount of cane to the MSC's factory.

Cane is hauled from the field to the mill either by bundled or basket trailers as bundled or loose cane. The bundled cane is carried by Single and Double Bundle type trailers while loose cane is carried to the mill by Single and Double Basket (bin type) trailers.

Cane transportation from the nucleus estate is mainly carried out by the company's (MSC) fleet. The truck types employed in hauling the cane from this area are mainly single basket trailers (popularly known as the nucleus estate trailers). Other trailer types are also at times allowed to haul cane from the nucleus estate but, this is a rare occurrence.

MSC's double and single bundle trailers, and all the contactors fleet haul cane from the Outgrowers' farms. The bulk of the cane delivered to the mills come from the outgrowers. In 1990/91 production for instance, the nucleus estate supplied 183,823 tones of cane while the outgrowers supplied 1,690,036 tones of cane (Matete and Mbai, 1991).

The project aims to study the material flow in MSC's factory Cane Yard and to model the system based on various operational rates. To improve the materials flow, the computer model developed would simulate the Cane Yard system of MSC factory and be available as an expert tool for guidance and more efficient engineering and managerial decision making. Once developed, such a model would be validated using the existing material flow data for sugar processing conditions prevailing at MSC.
By varying the model’s functional relationships and material flow parameters, it would be possible to project the best suited (optimal) material flow rates recommendable for the existing Cane Yard operating system. These variations in the model would help answer engineering and managerial questions such as:-

1. Are transport tractors adequate in number, capacity and mix?
2. Is Cane Yard capacity adequate in terms of transport and milling rates?
3. With regard to (1) and (2);
   (a) How are the cane quality and sugar production affected?
   (b) Could the night transport of sugar cane be eradicated?
   (c) Would offloading capacity improvement necessarily improve sugar output?

With regard to such important questions, the management, in the long term would be able to improve sugar production at Mumias Sugar Company.

1.1 Objectives

The main objective of this study was to model the Cane Yard operating system of MSC as an establishment of a base for the determination of optimal flow rates of input and output materials. To accomplish the main objective it was necessary to:-

1. Establish parameters characterising the flow of sugarcane from the field to the mills through the Cane Yard and model the same.
2. Validate and test the established model for its usefulness in utilising the existing material flow data and rates of operation.
2.1 Importance of the Sugar Industry

Sugar is an important foodstuff, not only as a source of calories but also as a sweetener which enhances taste. When grown in ideal conditions, there is no other crop which can provide an equivalent amount of energy from a given area of land. It is therefore no accident that the sugar industry has grown so rapidly in most countries (Kaplinsky, 1984).

Sugarcane has become an important crop, and what happens in relation to the processing technology is not an insignificant issue. Whilst the number employed in cane processing may be limited, the Agricultural labour force, particularly in un-mechanized cane farming, is often substantial (Kaplinsky, 1984). In addition, the investment tied up in cane growing and especially in processing, can be very large, often exceeding investment in any other single economic sector.

2.2 Status of the Sugar Industry in Kenya

The sugar industry plays an important role in the development of the Kenyan economy. This industry is one of the largest employers in the Agricultural sector (Awilly, 1990). As reported by Home (1991), the sugar industry dates back to the 1920's, though the Kenyan Government's participation started in earnest after independence. The Government has since then embarked on expansion programs that have led to commissioning of a number of new sugar factories. The major sugar factories in Kenya are given in Table 2.1 below.

Kenya's sugar industry performance has been declining while sugar consumption has been steadily increasing and this has resulted in occasional sugar shortages and often, the government has imported sugar. Several reasons have been given as the major cause of this decline. Among them are harvesting of over-mature cane, inadequate cane research and extension support services, inadequate cane supplies due to inadequate crop financing,
inappropriate high cost of investment and financial structures and cost arising from the
devaluation of the Kenya Shilling (Awilly, 1990)

Table 2.1: Major sugar factories in Kenya

<table>
<thead>
<tr>
<th>Factory</th>
<th>Started</th>
<th>Year</th>
<th>Current rated capacity of white sugar (tonnes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramisi*</td>
<td>1920's</td>
<td></td>
<td>30,000</td>
</tr>
<tr>
<td>Miwani</td>
<td>1922</td>
<td></td>
<td>60,000</td>
</tr>
<tr>
<td>Muhoroni</td>
<td>1966</td>
<td></td>
<td>55,000</td>
</tr>
<tr>
<td>Chemelil</td>
<td>1968</td>
<td></td>
<td>60,000</td>
</tr>
<tr>
<td>Mumias</td>
<td>1973</td>
<td></td>
<td>180,000</td>
</tr>
<tr>
<td>Nzoia</td>
<td>1978</td>
<td></td>
<td>60,000</td>
</tr>
<tr>
<td>Sony</td>
<td>1979</td>
<td></td>
<td>60,000</td>
</tr>
</tbody>
</table>

* Closed down in 1988

The performance of the Kenya Sugar Industry has been so poor that it is feared the country
might remain a net importer of sugar (Awilly, 1990). However, as reported by Home (1991), work done by Awiti (1989), suggested that in future Kenya should be self-reliant on sugar production. According to Awiti’s work, as stated by Home (1991), Kenya should have become self-reliant in sugar production by the end of the year 1991. The reported work by Home (1991), was based on the projections of consumption verses production of sugar in Kenya and the fact that at that time the Government of Kenya had promised to commission two new sugar factories in Busia and Siaya Districts. Kenya’s domestic sugar production, however, has declined tremendously and of the two new factories, Busia Sugar Company (BSC) was started but stagnated due to lack of funds while the second proposed factory in Siaya district is yet to be commissioned.

The actual performance of Kenya’s Sugar Industry therefore does not suggest any possibility of self-reliance in sugar production as reported by Home (1991). In fact between May and July, 1992, the situation in Kenya was so poor that sugar prices sky-rocketed to more than three times the government controlled price in most parts of the country. To avert this, large amounts of sugar had to be imported.
Despite the general poor performance of the sugar industry, MSC has maintained a steady annual production of well over 200,000 tonnes since 1986. This amounts to over 50% of the sugar produced domestically. Table 2.2 below shows the annual sugar production in Kenya from 1980 to 1988. Also shown in Table 2.2 is the quantity and percentage of sugar produced by MSC.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>By MSC</th>
<th>% By MSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>401,251</td>
<td>163,509</td>
<td>40.7</td>
</tr>
<tr>
<td>1981</td>
<td>368,970</td>
<td>167,402</td>
<td>45.4</td>
</tr>
<tr>
<td>1982</td>
<td>308,019</td>
<td>152,507</td>
<td>46.7</td>
</tr>
<tr>
<td>1984</td>
<td>372,114</td>
<td>175,375</td>
<td>47.1</td>
</tr>
<tr>
<td>1985</td>
<td>345,641</td>
<td>178,175</td>
<td>51.5</td>
</tr>
<tr>
<td>1986</td>
<td>365,796</td>
<td>205,642</td>
<td>56.2</td>
</tr>
<tr>
<td>1987</td>
<td>413,248</td>
<td>217,740</td>
<td>52.7</td>
</tr>
<tr>
<td>1988</td>
<td>426,000</td>
<td>219,005</td>
<td>51.4</td>
</tr>
</tbody>
</table>


2.3 System Simulation

A simulation model seeks to "duplicate" the behaviour of the system under investigation by studying the interactions among its components. The output of a simulation model is normally expressed in terms of selected measures that reflect the performance of the system (Taha, 1982).

Emshoff and Sisson (1970), defined simulation as a model of some situation in which the elements of the situation are represented by arithmetic and logical processes that can be executed on a computer to predict the dynamic properties of a situation. All simulation exercises require common functions. They summarised these functions as:-

1. Creation of random numbers and variates,
2. Recording data for output,
3. Performing statistical analysis on recorded data,
Simulation makes possible the systematic study of a problem when analytical solutions are not available and experiments on the actual system are impossible or impractical (Kobayashi, 1978).

A simulation model describes the operations of a system in terms of individual events of the individual elements in the system. The interrelationships among the elements are also built into the model (Kobayashi, 1978). Simulation is essentially a technique of conducting sampling experiments on the model of the system. Unlike the mathematical model, where the output of the model represents a steady-state behaviour, the results obtained from running a simulation model are observations that are subject to experimental error. Thus, inferences regarding the performance of the simulated systems must be subjected to appropriate tests of statistical analysis (Narsingh Deo, 1979).

By repeating the simulation experiments for various alternative system configurations and parameters, and comparing their performances, one may identify an optimal system structure (Kobayashi, 1978). The nature of simulation allows greater flexibility in representing complex systems that are ordinarily difficult to analyze using standard mathematical models. One must keep in mind, however, that the development of a simulation model is both time consuming and costly (Taha, 1982). Large and complex programs involved in constructing a simulation model are so demanding of time and effort that many investigators have little or no time left for validating the simulator, planning efficient execution, and correctly interpreting the simulation data (Emshoff and Sisson, 1970).

2.4 Simulation of Agricultural Production Systems

Simulation using a computer is a valuable tool for evaluation and analysis of physical and biological processes. Its history of application to defence and industrial problems date back to the 1940's. More recently it has found a place in Agricultural world, with the Agricultural Engineer leading the way in applications of simulation methodology to a wide range of problems (Sowell et al., 1975). Sowell et al., (1975) further reported that Link and Splinter
(1970) presented a survey of simulation techniques and applications to agricultural problems. They defined various terms associated with simulation and discussed different types of simulation.

As reported by Sowell et al., (1975), a cotton growth model was developed by Duncan (1972) and modified by Baker et al., (1973). It is based on conservation principles which include a carbohydrate balance, a moisture balance, and a nitrogen balance for the plant. Feedback loops are involved throughout the model. Daily output from the model include plant weight, the number of fruits, and the age of each fruit.

Sowell et al., (1975) developed a boll-weevil population model based on the life cycle of the insect using SIMSCRIPT programming language. The model consisted of the preamble, utilisation and the internal events sub-routines. The initialization round needed input data and scheduled the first day. Then it transferred the control to the timing mechanism. The results of simulation were reported daily or weekly, depending upon the amount of output desired. The output consisted of the number of adult weevils, number of pre-adult weevils, number of squares, number of bolls and the number of damaged fruit for each field. According to Csàbà Csáki (1985), Baker et al., (1976) developed a dynamic simulation model for corn production. This model consisted of three sub-models, namely, biological and physiological interrelations describing corn growth, soil cultivation, sowing operation and harvesting operations.

System simulation may be an appropriate means to study the process of animal husbandry with joint consideration of biological, technical and economic interdependence (Csàbà Csáki, 1985). As reported by Csàbà Csáki (1985), Graham et al., (1976) developed a simulation model of growth and production in sheep. The model was used to estimate daily balances of energy and nitrogen from the information about diet, animal and environment. To simulate broiler production, Greg et al., (1977) suggested the application of the various equations based on the live bird weight, the growth rate, the live weight gain for a specified period and the mortality rate expressed as a function of live weight and age.
In Western countries, a significant proportion of animal growth models are designed to satisfy the requirements of the agricultural extension service. Charlton and Street (1975) as reported by Csákó (1985) developed a dairy simulation model that analyzed the following:

1. The effect of possible future price changes on the way which growth could develop,
2. The effect in improvements in the technical performance of the stock and its management,
3. The effect of changes in farmer’s production system,
4. The effect of financial arrangement and interest levels.
5. The levels to which price and performance indices can fall before the dangers arise of being unable to meet any loan commitments.
6. The effect on growth of an increased level of consumption by the farmer and his family, and
7. The extent of advantages of having conservation growth policies, and maintaining adequate cash reserves in periods of fluctuating prices.

Alchalabi (1992) developed a simulation model for poultry ventilation rates and supplemental heating in winter. The development of this model was based on the basic equation used to determine air flow in many types of the engineering analyses for many years. The model results could be used effectively to evaluate and test different strategies, insulation, building size and bird density requirements.

Simulation modelling has also been widely applied in solving of problems in irrigating agricultural lands. As reported by Roberts et al., (1975), Lembke and Jones (1972) used simulation modelling technique as a method for modelling irrigation scheduling. Nderitu (1989) developed a simulation model for irrigation water scheduling in a study of the Mwea Irrigation scheme.
2.5 Simulation of Queuing Systems in Agriculture

Queues and congestion occur in all walks of life. In many industrial (agricultural industries included) and business environments the queues are of sufficient economic significance to warrant expenditure on their scientific studies. The mathematical foundation for queuing systems was laid down by A. K. Erlang through his study of the telephone service systems. A vigorous and systematic development as well as application of queuing theory to other areas begun in the 1950's (Deo, 1979).

In spite of a large body of elegant formulae in queuing theory, it is found that in most practical cases the situation is so complex as to preclude an analytical solution. In such complicated cases, and the MSC Cane Yard operations is such a case (see Section 4.2), one resorts to computer simulation (Kobayashi, 1978), (Taha, 1982), and (Narsingh Deo, 1979). Through simulation one can get numerical results for almost any queuing situation, a fact that is demonstrated by the wide application of simulation modelling technique to analyze various complex production systems.

Many researchers in Agricultural Engineering fields have used simulation modelling technique to analyze various agricultural processing systems in which the queuing elements are involved. Simulation modelling techniques have been employed widely in grain processing systems. Loewer et al., (1990) and Bucklin et al., (1989) reported that Bucklin et al., (1981), Khuri et al., (1988) and Breeden (1977 and 1979) used simulation techniques to model grain processing systems. Bucklin et al., (1989), developed a simulation model of the materials handling system in a seed bagging and processing plant. This was a dynamic model that evaluated the utilisation of the components of clearing and bagging systems. Output from the model included capacities and utilisation percentages of cleaners forklifts and labourers. Loewer et al., (1980) developed a simulation model for determining bottlenecks in an on-farm grain processing system. Loewer's model was used in identifying bottlenecks in grain harvesting, delivery, handling, drying and storage system. This model utilized graphics, histograms and performance statistics to measure and describe system performance and
identify the bottlenecks in a given system.

Williams et al., (1981) developed a computer simulation model for utilization of cotton gin as a fuel supplement for a coal-fired plant using the simulation language for alternative modelling (SLAM). This system model was a structured approach to the utilization analysis of cotton gin trash as an alternative energy source. It provided information on the feasibility of utilizing cotton gin trash in a coal-fired power plant. The utilization alternative was modelled as a combined discrete-continuous system. It was composed of three major subsystems namely: cotton harvesting, ginning, transportation and the power plant. The results of the simulation run indicated a potential use of cotton gin as an alternative energy source of coal-fired power plants.

Price et al., (1975) stated that simulation techniques for study of milking parlous are not novel. As reported by Price et al., (1975) and Sowell et al., (1975), Price et al., (1972) developed a simulation model for the milking parlour operations. The output from each computer simulation included four measures of parlour efficiency, namely, time required to milk a given number of cows, cows milked per man-hour, percent utilization of milking units and average time cows were in the stall. Also obtained from the simulation were two measures of man comfort namely, percent utilization of operator's time and frequency of having to leave the parlour pit to move cows. Price et al., (1972) developed another simulation model to simulate the milking rates in various semi-automatic milking parlours. The simulation model developed described two basic types of milking parlours, namely, the herringbone and the side opened.

Another area in Agricultural processing in which simulation modelling techniques have been employed is harvesting. Sowell et al., (1975) reported that Whitney (1972) developed a simulation model for corn harvesting. The model was used to analyze the effect of harvester idle time due to transport vehicle absence on the selected harvesting system. Sowell et al., (1970) developed a simulation model for mechanical harvesting operations of flue-cured tobacco. The output data for this model comprised of the time the harvester is harvesting,
turning, unloading, down due to failure and idle. As reported by Sowell et al., (1975), Winter and Groundwaters (1969) studied the assembly of grain at elevators in Western Canada using simulation modelling techniques. Millian and Rehkulges (1972) developed a simulation model to evaluate the effect of harvest date, harvesting rate and weather on the value of forage for dairy cows.

2.6 Selection of Simulation Languages

Construction of a simulation program is the most time consuming phase in simulation effort, and the use of a suitable simulation language is critical to the economic feasibility of the entire study (Kobayashi, 1978). Lambert (1975) stated that it is always possible to program a computer solution to a problem in a universal and general purpose language such as FORTRAN or COBOL. Efficiency of the user however, can often be enhanced by use of a computer software package of more specific design e.g SIMSCRIPT, GPSS, MPS, etc.

In considering a preferred language to use for a certain task, Lambert (1975), Kobayashi (1978) and Deo (1979) state that two basic questions should be answered:

1. Should a general purpose language e.g FORTRAN, or a specific purpose software e.g SIMSCRIPT, be used?
2. If a special software package is preferred which one should it be?

Specialised simulation languages fall into two categories: continuous and discrete (Lambert, 1975). A detailed discussion on applications, advantages and disadvantages, of various types of discrete simulation languages have been presented by Sowell et al., (1975), Lambert (1975), Emshoff and Sisson (1970), Shaw and Molnan (1975), Kobayashi (1978), Price et al., (1975), Sowell et al., (1975), Fishman (1978), Deo (1979) and Krasnow (1968) among others. A listing of seven discrete simulation languages together with the computers on which compilers or translators are available, and the developers of the language can be found in Sowell et al., (1975).
As stated by Lambert (1975), the expected future use of a program should seriously be considered when the choice between a general language and a specialized software package is being made. Researchers, extension workers and others who may be sharing programs as part of a team effort often face the use of the program on various hardware. Many of the specialized software packages are available only on certain machines, so that often widely shared programs should be written in a universal language.

Sometimes it is difficult for the user to decide which language to choose for a particular application. According to Sowell et al., (1975), factors which should be considered in making this decision are:

1. Nature of the problem and orientation of the languages available,
2. Availability of an intelligently written user's manual,
3. Ease of programming the language and the analyst's programming expertise,
4. Availability of language support from a major interest group which will correct, update, and improve the compiler or translator,
5. Availability of error diagnostics, and
6. Cost of compiling and running programs written in the language.

In view of the above, the simulation program for this study was developed in Turbo PASCAL (version 5.5) since none of the problem oriented languages were available in the computer on which the simulation program was to be developed. Secondly, since the simulation program was developed at Mumias Sugar Company, Mumias, a general programming language had to be used as the model is to be used to assess the effects of several input variables on MSC Cane Yard operations on other computers at the Agricultural Engineering department in the University of Nairobi. Program modification is also unlikely to take place at Mumias.

The advantages of PASCAL as a general purpose programming language have been summarised by Wolfgang Kreutzer (1986) as:-
1. Good PASCAL compilers are widely (and cheaply) available on both large frame and personal computers,
2. PASCAL offers flexible, safe control and data structure, encouraging good coding styles,
3. PASCAL allows user-definable types and flexible rules for naming object.

2.7 Cane Yard Studies at Mumias

Cane flow within the MSC Cane Yard has been a source of concern to the management of MSC. There is a consensus that the operations in the yard are major bottleneck sources to a smooth cane flow. The diversity of the unloading equipment operating in the yard, and their interactions, make an understanding of the Cane Yard operations difficult.

Suttie (1979) in a report on Cane Transport, Reception and Field Workshop operations stated that there was a potential to improve on the yard operations. His recommendation on cane reception was that all areas required discipline tightening up and that the Gantry cranes and wheeled loader (CAMECO) operators required training to improve their efficiency, and reduce excessive wear and damage. On Hydro-loaders, Suttie recommended that the use of this equipment be optimized and inspections on the chain net (basket) trailer be improved to ensure that all nets are in proper conditions before the unit is cane loaded. Finally, he recommended the use of automatic trip chain grip for the bundled cane units and the extension of the Gantry cranes bay both to the east and west plus adding a fifth Gantry crane to ease the unloading of bundle type trailers.

Most of the Suttie’s recommendations were implemented and an improvement of the yard operations was attained to some extent (Kamau, 1991). However, the waiting time of units, particularly, the bundle units was observed to be still a problem. May be this could also have been lowered if the fifth Gantry crane was commissioned as recommended by Suttie (1979).
As reported by Kamau and Jackson (1986), the MSC Agricultural Services report of 1984 and 1985 contained adverse comments concerning Cane Yard trailers waiting times. During that period, the average per unit waiting time was reported to have been well above the allowed waiting time limit of 30 minutes (per unit). Suttie (1979) reported that in November 1979, a single bundle unit on average had a waiting time of 62 minutes on each trip. According to Kamau and Jackson (1986), the final report on Cane Transport (1985) estimated that the trailers spent a total of 53000 hours in the Cane Yard, representing 1.5 million Kenya shillings in 1984/85 production year.

Observation on traffic movement in the Cane Yard showed that, traffic generally does not follow any laid down plan, particularly when there is a mill or an unloading equipment breakdown. The result of this unplanned movement is the excessive waiting time of the units in the yard. The waiting time of the bundled cane units is made unnecessarily long due to jostling among the contractors' units. There seemed to be no queue discipline for the contractors' drivers with bundle type trailers during peak cane delivery periods (i.e between 12 p.m and 3 p.m) as every driver, once in the yard struggles to reach the service point. The high waiting time for the bundle cane units may also be attributed to lax attitude that was observed with some chain men who at times appear to be unconcerned of how long it takes them to load back the chains on to the trailer.

In an attempt to reduce the Cane Yard average waiting time of the bundle trailers, Kamau and Jackson (1986) developed a queuing model for the Gantry cranes unloading system using the standard queuing equations. From the model the mean waiting time was found to be 38.8 minutes which is well above the usually budgeted waiting time per unit of 30 minutes. Such a simple approach however, could not have produced accurate results as other activities that affect the Gantry crane unloading operations are known to exist and could not be incorporated using the simple queuing approach they applied. They therefore went further and attempted to develop a computer simulation model that would take into account the Cane Yard component interactions, but the data obtained could not stand up to accurate statistical analysis. As a result, Kamau and Jackson (1986), recommended that a new computer
simulation model be developed that would help form a clear picture of the Cane Yard operations. It is on the basis of their recommendation that this study was undertaken with a view to developing a complete Cane Yard simulation model.
CHAPTER 3: THEORETICAL CONSIDERATIONS

The appearance of simulation methods in Agriculture has grown in parallel with the spread of systems analysis and with an increasing demand for a more and exact understanding of the real world (Csàbà Csàki, 1985). The fact that production processes of agriculture are dynamic in nature, influenced by random effects, and based upon biological principles, means that they are suitable for study using systems approach based on simulation.

Systems approach and simulation methods are now used in almost every field (Csàbà Csàki, 1985). Because of the highly complex nature of the operating systems modelled by simulation; understanding the simulation methodology is challenging to both the practising managers and researchers. A detailed discussion of simulation methodology have been presented by the following authorities: Wolfgang Kreutzer (1986), Csàbà Csàki (1985), Kobayashi (1978), Emshoff and Sisson (1970), and Naylor et al., (1968), among others. Work done by these authorities indicate that the logic of simulation are similar in almost all cases. The flow chart presented in Figure 3.1 gives the nine aspects of simulation methodology as presented by Wolfgang Kreutzer (1986).

From the view point of simulation there are two fundamentally different types of systems, namely:-

1. Systems in which the state changes smoothly or continuously with time - continuous systems, and
2. Systems in which the state changes abruptly at discrete points in time - discrete systems.

A queuing situation, like MSC Cane Yard system (see 4.2) in which cane trailers join or leave the queue only in discrete numbers is an example of a discrete system. Most studies of communication, transportation and computer systems involve discrete system simulation.
Figure 3.1: Nine aspects of simulation methodology (Source: Wolfgang Kreutzer, 1986)

Usually, the simulation of most Engineering and Physical sciences turn out to be continuous where as most systems encountered in Operations Research and Management Science are discrete. In discrete systems, the changes in the state (at discontinuous points) are called events. An arrival or departure of a customer (and, in this study, a trailer) in a queue is an event. As a result the simulation of a discrete system is usually referred to as discrete-event simulation (Narsingh Deo, 1979).
3.1 Discrete-event Simulation

Discrete-event simulation is commonly used by Operation Researchers to study large, complex systems which do not lend themselves to conventional analytic approach. In simulating these systems there are two fundamentally different models for moving system through time. These models are:

1. The fixed time-step model, and
2. The event-to-event (next event) model

In a fixed time-step model a 'timer' or clock is simulated by the computer. This clock is updated by a fixed time interval $\tau$ and the system is examined to see if any event has taken place during this time (minutes, hours, day etc). All the events that take place during this period are treated as if they occurred simultaneously at the end of this interval. In the next event simulation model the computer advances time to the occurrence of the next event. It shifts from event to event. The system state does not change in between. Flow charts for these two methods of simulating a discrete event system in their most general form is shown in Figure 3.2. According to Deo (1979), in most simulations of discrete systems, the next event model is used since the times taken to accomplish an event and hence the occurrence of another event are stochastic in nature. The only draw back of the next event model is that its implementation (programming for it) turns out to be more complicated than the fixed time-step model.

The stochastic nature of the next-event simulation system means that there exists an inherent random or unpredictable behaviour in these systems. In stochastic systems, at least one of the variables (that affect the system's behaviour) is given by a probability function. To simulate such random variables, a source of randomness is required. In simulation experiments, this is achieved through a set of uniformly distributed random numbers. These numbers are samples from a uniformly distributed random variable between some specified interval with equal probability of occurrence. A random number generator and its appropriate
use forms the heart of any simulation experiment involving a stochastic system (Deo, 1979).

Figure 3.2: Flow charts for discrete system simulation.  
(Source: Narsingh Deo, 1979 page 41)
3.1.1 Generation of Random Numbers

In simulation models, sampling from any probability distribution is based on the use of \([0,1]\) random numbers. For the sequence of random numbers generated to be truly random, it must satisfy the following two conditions:

1. All (continuous) values generated in the interval \([0,1]\) are equally likely to occur, and
2. Successive values are generated in the interval \([0,1]\) in a completely random fashion, meaning that they are independent and un-correlated.

In simulation studies, random number generators that are based on electronic sources are often used to generate the required random number sequences (Deo, 1979). The random number generators based on electronic sources rely on mathematical recursive relationships. The random numbers based on mathematical relations are, however, not truly random, as the sequence is completely deterministic. These sequences, however, pass most statistical tests. Numbers generated using mathematical procedures are referred to as pseudo-random numbers. One of the most widely used techniques for generating the pseudo-random numbers is the multiplicative congruential method. A detailed discussion on the generation of \([0,1]\) random numbers using this method can be found in Emshoff and Sisson (1970), Fishman (1978), and Kobayashi (1978) among others.

3.1.2 Generation of Variates for Simulation

Several methods exist for generating a sequence of random observations from a given probability distribution (Kobayashi, 1981). Among these methods, the Inverse Transform method, the Rejection method and the Rectangular approximation method are the most frequently used methods (Emshoff and Sisson, 1970).
The Inverse Transform Method

Let $X$ be the random variable of our concern and $F(x)$ be the distribution function, that is

$$F(X) = P(X \leq x) \quad \ldots (3.1)$$

Set $F(x) = Y$, then $Y$ is defined over the range 0 and 1. If $Y$ is a random variable uniformly distributed between 0 and 1, the variable $X$ is then defined by

$$X = F^{-1}Y \quad \ldots (3.2)$$

and has the cumulative distribution $F(x)$. The inverse mapping $F^{-1}(\cdot)$ can be done by writing the equation for this function or by developing a table giving values of $X$ for a finite (but sufficiently dense set of points of $Y$ from 0 to 1). According to Deo (1979), Fishman (1978), Kobayashi (1981) and Taha (1982), if $X$ is a random variable with the exponential distribution

$$F(X) = 1 - e^{-\mu x}, \quad x > 0 \quad \ldots (3.3)$$

then applying the above procedure, and setting the above function equal to a random variable $Y$

$$Y = 1 - e^{-\mu x} \quad \ldots (3.4)$$

$$X = F^{-1}(1 - Y) = \frac{-\ln(1 - Y)}{\mu} \quad \ldots (3.5)$$

where $\mu = \text{mean of the variable } x$.

Since $1 - Y$ is itself a random decimal number between 0 and 1, one can use a simpler transformation

$$X = F^{-1}(1 - Y) = \frac{-\ln Y}{\mu} \quad \ldots (3.6)$$

Thus, one can generate a sequence of random observations from an exponential distribution by applying the transformation (3.5) or (3.6). The algorithm of the logarithmic transform has the advantage of being easy to program (Fishman, 1978).
The inverse transformation method, although simple in principle, is often difficult to apply for many probability distributions because one cannot find a mathematical expression for the inverse function $F^{-1}$. In such cases, the Rejection method which does not require an explicit expression for $F^{-1}$ can be used.

The rejection method

This method relies on repeated sampling until a specified condition occurs. In this method, let $f(x)$ be the probability density function bounded by $M$ and have a finite range (or support), say $a \leq x \leq b$, as shown in Figure 3.4.

If one generates a pair of decimal random number $(R_1, R_2)$ between 0 and 1 then

$$X_1 = a + (b - a) R_1 \quad \ldots (3.7)$$

is a random number in $[a, b]$. Whenever one encounters a pair of random numbers $(R_1, R_2)$ that satisfies the relationship

$$MR_2 \leq f(X_1) ; \quad \ldots (3.8)$$

Figure 3.3: The exponential distribution curves

\begin{align*}
\text{(a) Density function} & & \text{(b) Distribution function}
\end{align*}
one accepts $X_1$ and rejects otherwise. The probability density function of $X_1$'s accepted is then $f(x)$.

The number of trials before a successful pair is found is a random variable $n$ with a geometric distribution (Kobayashi, 1978),

$$P[n] = \rho (1 - \rho)^{n-1} \quad \ldots (3.9)$$

with

$$\rho = \frac{1}{M(b - a)} \quad \ldots (3.10)$$

Its mean variable $n$ is

$$E[n] = \frac{1}{\rho} = M(b - a) \quad \ldots (3.11)$$

Figure 3.4: The rejection method to generate a random variable with the probability density function $f(x)$. The point 'O' is to be accepted, whereas point 'x' is to be rejected (Source: Kobayashi, 1978)
Equation (3.11) implies that this method may not be efficient for density functions with large \( M(b - a) \). To avoid the inefficiencies of the rejection method, the method of **Rectangular approximations** is usually used.

**The rectangular approximation method**

This method is used when no explicit functional form represents the probability density function. Instead, the probability function of the distribution is approximated by a set of rectangles. Such a probability density function together with its corresponding cumulative distribution is shown in Figure 3.5. The widths of the rectangles are proportional to the range of observed values \( x \) to \( x + \delta \) and the heights are proportional to

\[
\int_{x}^{x+\delta} f(x) \, dx
\]  

...(3.12)

When the rectangular approximation have been completed, the cumulative density function (CDF) can be derived.

The cumulative density function can then be used to generate random variables. For instance if

\[
F(x_1) \leq r \leq F(x_2)
\]  

...(3.13)

then the variate \( x \) would be approximated by the following linear interpolation

\[
X = x_1 + (x_2 - x_1) \frac{r - F(x_1)}{F(x_2) - F(x_1)}
\]  

...(3.14)

This method can also be used for discrete distributions in which the variable takes only specific, discrete values and a probability is associated with each. The cumulative distribution is rectangular in this case and \( X \) is found by generating \( r \) and doing a table look-up to determine \( F(r) \).
Since the rectangular approximation method requires fewer random numbers than the rejection method, it is usually, but not necessarily, more efficient. The trade-offs between the methods depend on the form of the probability distributions (Emshoff and Sisson, 1970).

3.2 Simulation of Queuing Systems

In any queuing system, when the arrival rate and service rate do not exactly correspond, queues are likely to develop or the service facility remains idle. In such a system, long queues means wastage of time while indiscriminate duplication of service facilities to eliminate all queues is not a solution because of the loss in terms of idle time of the service facility. A queuing problem is therefore a problem of balancing the cost of waiting against
the cost of idle time for the service facility in the system. This balancing act requires an analysis of the queuing system which means determining various statistics such as the service facility idle time, average waiting time, queue length, etc, for the various conditions. The queuing problem arises due to stochastic nature of the times between arrivals of customers (in this study, the arrival of cane trailers) as well as the time it take to service a customer.

The important parameters in a queuing system are:

(i) The arrival pattern of customers, i.e, frequency distribution of inter-arrival times,
(ii) The service time pattern, i.e, frequency distribution of the service times,
(iii) The number of servers (or service counters or service channels), and
(iv) The queue discipline, i.e, the order in which service is provided such as First-Come-First-Served, (FCFS), also called First-In-First-Out, (FIFO), Last-Come-First-Served (LCFS) or some priority system.

3.2.1 The arrival pattern of customers

The simplest arrivals that one might think of at first is the regular arrivals. In this arrival pattern, customers arrive at equally spaced instants, say $\tau$ units of time apart. In such a case, the arrival rate of customers is

$$\lambda = \frac{1}{\tau} \quad \ldots (3.15)$$

per unit time. According to Kobayashi (1978), the assumption of regular arrivals, however, is not only unrealistic in most actual applications, but is also not the easiest to deal with mathematically. The simplest and most useful model of arrival pattern is the completely random arrival process usually called the Poisson arrival process.
Poisson arrival process

This distribution is based on the assumptions that:

1. The inter-arrival times of the customers are such that there is a fixed long-term average time gap between two arrivals. Let this time be $\alpha$,
2. Customers arrive independently, and
3. The probability of an arrival during any period depends only on the length of that period.

Therefore the probability of a customer arriving during a very small slice of time $h$ is $h/\alpha$. Hence the probability of a customer not arriving during a very short time $h$ is

$$\left(1 - \frac{h}{\alpha}\right) \quad \ldots (3.16)$$

If,

\[
\begin{align*}
    f(t) &= \text{probability that the next customer does not arrive during the interval } t \text{ given that the previous customer arrived at } t = 0, \text{ and likewise} \\
    f(t + h) &= \text{probability that the next customer does not arrive during the interval } (t + h) \text{ given that the previous customer arrived at } t = 0,
\end{align*}
\]

then, since the arrival of customers in different periods are independent events (i.e the queue has no memory) we can write,

$$f(t + h) = f(t) \left(1 - \frac{h}{\alpha}\right) \quad \ldots (3.17)$$

or

$$\frac{f(t + h) - f(t)}{h} = -\frac{f(t)}{\alpha} \quad \ldots (3.18)$$
Taking limits on both sides as h tends to zero we get

\[ \frac{df(t)}{dt} = -\frac{f(t)}{\alpha} \] \hspace{1cm} ...(3.19)

The solution to Equation (3.19) is

\[ f(t) = ce^{-\frac{t}{\alpha}} \] \hspace{1cm} ...(3.20)

Since at \( t = 0 \), an arrival has just taken place, the probability of a non-arrival at \( t = 0 \) is 1.
That is, \( f(0) = 1 \) and therefore the constant \( c \) in Equation (3.20) is unity. Thus,

\[ f(t) = e^{-\frac{t}{\alpha}} \] \hspace{1cm} ...(3.21)

Equation (3.21) give the probability that the next customer does not arrive before time \( t \) has elapsed since the arrival of the last customer.

The probability that a customer arrives during an infinitesimal interval between \( t \) and \( \delta t \) is given by the product of:

(i) the probability that no customer arrives before time \( t \), and
(ii) the probability that exactly one customer arrives during \( \delta t \).

This product is

\[ e^{-\frac{t}{\alpha}} \left( \frac{\delta t}{\alpha} \right) \] \hspace{1cm} ...(3.22)

which means that the probability density function of the inter-arrival time is

\[ \frac{1}{\alpha} e^{-\frac{t}{\alpha}} \] \hspace{1cm} ...(3.23)

The integral

\[ \frac{1}{\alpha} \int_0^t e^{-\frac{t}{\alpha}} dt = 1 - e^{-\frac{t}{\alpha}} \] \hspace{1cm} ...(3.24)
is the probability distribution function. The curves of Equations (3.23) and (3.24) are shown in Figure 3.3. The curve in Figure 3.3(b) gives the probability that the next customer arrives by time $t$, given that the preceding customer arrived at time zero.

Having established that the inter-arrival time is governed by the exponential distribution, we now find the probability that $k$ customers have arrived during the interval $t$ (assuming that no customer had arrived by time $t = 0$).

Let $q_k(t)$ be the probability that exactly $k$ arrivals take place between the start time zero and $t$, for $k = 1, 2, \ldots$. Then we can write

$$q_k(t + h) = f(t) \frac{h}{\alpha} + q_k(t) \left(1 - \frac{h}{\alpha}\right) \quad \ldots (3.25)$$

$$= \text{(Probability that no arrivals take place between time zero and } t) \times \text{(Probability that one arrival takes place during } h) + \text{(Probability that one arrival takes place between time zero and } t) \times \text{(Probability that no arrival takes place during } h)$$

where

$$f(t) = e^{-\frac{t}{\alpha}}$$

Therefore

$$\frac{q_1(t + h) - q_1(t)}{h} = \frac{1}{\alpha} [f(t) - q_1(t)] \quad \ldots (3.26)$$

as $h$ approaches zero (0), Equation (3.26) becomes

$$\frac{dq_1(t)}{dt} = \frac{1}{\alpha} [f(t) - q_1(t)] \quad \ldots (3.27)$$

The solution to Equation (3.27) is

$$q_1(t) = \frac{t}{\alpha} e^{-\frac{t}{\alpha}} = \frac{t}{\alpha} f(t) \quad \ldots (3.28)$$

Extending the same argument (since at most one arrival can take place in the interval $h$) we get
It can be seen that, in general

\[
\frac{q_k(t)}{dt} = \frac{q_{k-1}(t) - q_k(t)}{\alpha} \quad \ldots \quad (3.30)
\]

Solving Equation (3.30) successively (i.e for \(k = 1, 2, \ldots\)) results in

\[
q_k(t) = \left( \frac{t}{\alpha} \right)^k \frac{1}{k!} e^{-\frac{t}{\alpha}} \quad \ldots \quad (3.31)
\]

Expression (3.31) is called the *Poisson distribution formula*. Curves for \(q_k(t)\) for several values of \(k\) are shown in Figure 3.6.

From the foregoing analysis, it can be seen that if the inter-arrival time is distributed exponentially, then the number of arrivals is given by the *Poisson distribution*. In a *Poisson distribution*, the outcome is expressed as the number of events \(k\) occurring in a time period \(t\).

![Figure 3.6: Poisson distribution curves (Source: Narsingh Deo, 1979)](image-url)
Taha (1982) and Deo (1979) state that a Poisson distribution can be sampled by using the relationship between it and the exponential distribution.

3.2.2 Generation of Poisson variates

In a Poisson distribution, the probability of an event occurring exactly $k$ times during a given time interval $t$ is given by the probability mass function

$$g_k(t) = (t\lambda)^k \frac{1}{k!} e^{-t}$$

...(3.32)

where

$\lambda$ = the average number of times the event occurs in a unit period (say one hour)

Putting $t = 1$, we get,

$$g_k = \frac{(\lambda)^k}{k!} e^{-\lambda}$$

...(3.33)

In order to find values of $k$ (the number of arrivals per unit time) drawn from the probability mass function (3.32), the relationship between the exponential and Poisson distributions is used.

If we generate exponentially distributed time intervals $t_1, t_2, t_3, \ldots$ with the expected (average) value equal to $1/\lambda$ (say per hour), and then add the time intervals as

$$t = t_1 + t_2 + t_3 + \ldots$$

...(3.34)

till their sum $t$ exceeds 1, then we stop and count how many $t_i$'s were added just before their sum exceeded 1 (e.g one hour) the count $k$ is then precisely the random sample from the Poisson distribution. Equation (3.34) can be expressed as

$$t_1 + t_2 + t_3 + \ldots + t_k \leq 1 < t_1 + t_2 + t_3 + \ldots + t_{k+1}$$

...(3.35)

According to Deo (1975) and Taha (1982), these exponentially distributed variates $t_i$'s can be generated by applying the Transform method (see Section 3.1.2). The transform equation
for generating the interval times is

\[ t_i = -\frac{1}{\lambda} \ln R_u \]  \( \ldots (3.36) \)

where

\[ R_u = \text{uniformly distributed [0, 1] random numbers}. \]

Thus, by generating \( t_i \)'s according to Equation (3.36) and counting how many of them occurred within one time unit, in accordance with Equation (3.35) gives the number of random values \( k \). In this case, successive interval times are sampled until the sum of \( t_i \)'s exceeds 1 for the first time. The number of arrivals is then the number of \( t_i \)'s sampled during time interval less one.

3.2.3 Service time distributions

Although there are theoretical results connected with queuing processes that can be carried through with a general service distribution, in practice it is useful to assume that the distribution is of some special type that can be characterised by a few parameters (Kobayashi, 1978). Some of the distributions that are used to sample service times are:-

1. The exponential (also called negative exponential) distribution,
2. The Gamma distribution,
3. The Erlang distribution, and
4. The Hyper-exponential (or Mixed exponential) distribution.

According to Kobayashi (1978) and Taha (1982), among these distribution functions, the exponential distribution is the mathematically simplest and most appropriate distribution function that is used in practice to sample service times.
The exponential distribution function is defined in Section 3.1.2 by Equation (3.3) and plotted in Figure 3.3(b). The generation of the exponential variates is carried out by applying the Inverse transform method (see Sections 3.1.2 and 3.2.2).

To completely define a queuing system, the queue discipline and the number of servers or service channels are established in addition to the inter-arrival and service time distributions. This is followed by the development of the flowcharts for each sub-system of the system to be modelled. The flowcharts are then converted to a simulation model by writing a program in the selected language. The simulation model is then verified. According to Horn (1968), verification ensures that a simulation model behaves as the experimenter intends. Once the model is verified, validation or credibility tests of the model is established. Validation tests the agreement between the behaviour of the simulation model and the real system (Deo, 1979; Kobayashi, 1978 and Horn, 1968)

3.3 Validation of a Simulation Model

Validation is the process of building an acceptable level of confidence that an inference about a simulated process is a correct or valid inference for the actual process (Horn, 1968). In order to draw an inference about the real system from results obtained from the simulation, the model must be a reasonable valid representation of the real system (Kobayashi, 1978). Deo (1979) states that there is no simulation model that duplicates the given system in every detail. This is supported by Horn (1968) by stating that seldom, if ever, will validation result in a 'proof' that the simulator is a correct or 'true' model of the real process. The validation process may be for an existing or a first-time model (Deo, 1979).

3.3.1 Validating existing systems

When the simulated system exists in real life, the best approach is to use the real world (historical) data as inputs to the model and compare its output with that of the real system. This process of validation according to Deo (1979) and Kobayashi (1978) is straightforward
in principle but may present the following problems:

1. It may not always be easy to obtain input and output data from the real system without disturbing it,
2. Even if we could get actual input/output data of the existing system it may not generally be for long periods, and
3. Establishing that the model output and the real system outputs are from the same population.

If outputs to be compared are sample means (e.g. average queue lengths, waiting times, idle times, etc), then the available goodness of fit tests such as Chi-square, $\chi^2$, and the Kolgomorov-Smirnov tests among others can be used to measure the discrepancy between the two outputs (i.e. the model and the real system outputs). Also hypothesis testing can be used to determine if any significant differences exist between, say, the average independent set of observations (Deo, 1979).

### 3.3.2 Validating first-time model

If a model is intended to describe a proposed or hypothetical system, then the task of validation is more difficult as there are no historical data available to compare its performance with. Hypothetical systems by nature are based upon assumptions and it is the validity of these assumptions the simulation model is dependent on. According to Deo (1979) and Emshoff and Sisson (1970), a number of guidelines have been found useful in validating such models. These are:

1. **Sub-system validity**: The model itself may not have an existing system to compare it with, but may consist of known sub-systems each of whose validity can be tested separately.
2. **Internal validity:** There is a tendency to reject a model if it has a high degree of internal variability. A stochastic system with high variance due to its internal processes will tend to obscure changes in the output due to input changes.

3. **Sensitivity analysis:** Sensitivity analysis consists of systematically varying the values of parameters or the input variables one at a time (while keeping all others constant) over some range of interest and observing the effect upon the model's response. Sensitivity analysis determines the parameters (or input variables) to which the system is more sensitive.

4. **Face validity:** If the model goes against the common sense and logic, and those with experience and insight into similar systems do not judge the model as reasonable, it should be rejected.
CHAPTER 4: MATERIALS AND METHODS

4.1 Sugar Cane Harvesting and Loading

All the cane supplied to the MSC’s sugar factory is cut by hand with a cane knife or a machete. Once cut, the cane is either arranged to form a stack or put into a windrow. On average a stack of cane weigh about six (6) tonnes (Kamau, 1991).

The stacked cane is loaded into single bundle trailers with the help of side-loading winches in the field. Under very wet conditions, infield transport of the loaded trucks is a major problem as traction is highly reduced. To alleviate this problem, plain-winches are used to tow the cane loaded trucks until the trucks reach a feeder road on which wheel slip is not a major problem. The loaded single bundle trailers then haul the stacks to a transloading site at which the bundled stacks are transferred onto double bundle trailers which then haul the bundles to the mill. In some instances, the single bundle trailers haul the bundles directly to the mill. The windrowed cane is loaded into basket type trailers which transport the cane directly to the mill. A similar procedure is employed (as in the case of single bundle trailers) for in-field transport of the basket type trailers. A single basket trailer carry on average seven tonnes of cane while a double basket carries twelve (12) to thirteen (13) tonnes (Kamau, 1991).

4.2 Plant Layout and Operations

In a sugar manufacturing establishment, like MSC, transport and unloading capacities should be designed to supply the daily grinding capacity of the mills irrespective of the machines used. Cane transport and unloading rates determines the required number of transport trailers to be used in hauling cane from the fields to the mills (Shukla et al., 1972). According to Kamau (1991), the flow rates of sugarcane from the fields to the MSC factory through the Cane Yard have been observed to be dependent on the following factors:
1. Trailer and unloading equipment type,
2. Available unloading capacity,
3. Hour of operation, and
4. Weather (dry or wet conditions)

MSC sugarcane flow through the processing system is presented in Figure 4.1.

In this study, the area referred to as the Cane Yard in Figure 4.1 forms the system to be modelled. This is the area between the weighbridges (WBA and WBB) and the Mill Table (MLTA and MLTB) and is where unloading of the cane loaded trailers take place. The Cane Yard forms the link between transport and factory operations. Therefore it can be said that Cane Yard operations directly affect the performances of the sugarcane processing system. As a result, if the Cane Yard is inefficiently operated then it will have an undesirable effect on the overall performance of the sugarcane processing system whereas if it efficiently operated it will enhance the sugarcane processing operations. This study was aimed at establishing whether or not the MSC Cane yard operations are a bottleneck to the efficient operations of the sugarcane processing system.

As presented in Figure 4.1, cane loaded trailers arriving from the fields are weighed-in on weighbridges WBA and WBB before entering the Cane Yard. Arriving cane loaded trailers are weighed in on First Come First Served (FCFS) basis. When the arrival rate of cane loaded trailers is higher than the serving (weighing-in) rate of the weighbridges, queues of cane loaded trailers develop behind the two weighbridges. The development of these queues, however, should not be taken to mean that the weighing-in process is a bottleneck to the Cane Yard operations at all times when these queues are observed. The observed queues are in most cases caused by the inefficient Cane Yard operations.
The inefficiencies in Cane Yard operations are experienced when any of the following occur singly or in combination:

1. Mill breakdowns,
2. Unloading equipment breakdowns,
3. Unmatched unloading capacity to cane transport trailers.

From Figure 4.1, once a cane loaded trailer has been weighed-in, it enters the Cane Yard and heads for its service (unloading) point. At the unloading point, an arriving trailer is unloaded immediately if the there is no queue or joins the service queue and waits for its turn to unload. A service queue for a given trailer type could be:
1. SSQTT  - Self-tipping trailers service queue.
2. SQHYDA  - Mill A basket trailers service queue.
3. SQGC  - Gantry cranes service queue for ordinary bundle trailers.
4. SQHYDB  - Mill B basket trailers service queue.
5. SQHYDC  - service queue for basket trailers weighed-in through any of the two weighbridges waiting to be unloaded into area A3 by HYDC.

At the unloading point, the unloading operation for a given trailer type and the unloading equipment is based on First-Come, First-Served (FCFS). The movement of cane in the yard for the loaded and unloaded trailers is presented in Figure 4.2. As presented in this figure, all cane trailers once unloaded, proceed to the weighbridges and are weighed-out. A cane trailers that was weighed-in through WBA is weighed-out through WBA and one that weighed-in through WBB is weighed-out through WBB. The use of one weighbridge by a trailer is to enable one to determine the amount of cane that a trailer carried. The difference in weight between a cane loaded trailer and an empty one gives the weight of the cane that was carried by the trailer. The various unloading equipment in the MSC Cane Yard are shown in Figures 4.1 and 4.2.

In studying the operations for a real life system such as the MSC Cane Yard, Kobayashi (1978) states that the whole system should be divided into smaller but, manageable sub-systems. In the MSC Cane Yard, a trailer’s service (unloading) point is solely dependent on the trailer type. This is due to the fact that a given trailer can only be unloaded by a specified unloading equipment. Three sub-systems based on the trailer type and the unloading equipment that describe the MSC Cane yard operations can be formed. These sub-systems are:

1. Basket (bin) trailers - Hydro-Loader subsystem,
2. Self-tipping trailers subsystem, and
3. Ordinary bundle trailers - Gantry cranes subsystem.
Figure 4.2: Schematic representation of MSC Cane Yard traffic flow
4.2.1 Basket trailers - Hydro-Loader subsystem

The three service queues designated SQHYDA, SQHYDB and SQHYDC in Figures 4.1 and 4.2 are queues of basket (bin) trailers waiting to be unloaded by Hydro-Loader HYDA, HYDB, and HYDC. A typical service queue for a Hydro-Loader is presented in Figure 4.3 with one unit (trailer) in service. HYDA and HYDB unload the cane from the basket trailers onto Mill Tables MLTA-1 and MLTB-1 respectively. A typical Mill Table condition just after completion of an unloading operation is shown in Figure 4.4.

![Figure 4.3: Typical queue of basket trailers behind HYDA during normal factory operation](image)

During the normal factory operations (i.e when both Mills A and B are crushing at their optimum capacities), all basket trailers are unloaded by HYDA and HYDB. For a double basket trailer, each bin (compartment) is unloaded separately, one after the other. The unloading operation of a double basket trailer is presented in Figure 4.5. The unloading operations of the basket trailers is based on FCFS at the three unloading points.
The third Hydro-Loader (i.e HYDC) is a stand-by basket trailers unloading equipment and is only operated when any of the following situations arise singly or in combination:

1. One mill (or both) is not operational due a breakdown resulting in long queues developing behind the mill’s Hydro-Loader.
2. One mill is due for maintenance thus the operating mill cannot cope with the basket trailer inflow rates.
3. Operational problems in the Mills or Process houses.

Hydro-Loader C (HYDC) unloads the cane over the roll-over steel wall onto the ground in area A3 in Figure 4.2. The unloaded cane is then push-piled by the Front-End-Wheel loader away from the unloading (service) point. Figure 4.6 shows this Hydro-Loader in operation.
From the foregoing description together with Figures 4.1 and 4.3, the Basket trailers - Hydro-Loaders subsystem can be represented by Figure 4.7. This subsystem can be described by three separate but identical single-queue, single-server queuing system models (Heinze, 1982). Each service queue and its unloading Hydro-Loader being taken separately.

Figure 4.5: Unloading operation of a double basket trailer
Figure 4.6: Unloading operation of a basket trailer by HYDC

Figure 4.7: The basket trailers - Hydro-Loaders subsystem
5.2.2 The Self-tipping trailers sub-system

This sub-system does not comprise of a separate unloading equipment as is the case in 5.2.1. Instead, the Self-tipping trailers are fitted with hydraulic rams which are used to tip the trailer onto one side to unload the bundled cane. The Self-tipping trailers unload their cane in area A1 shown in Figures 4.1 and 4.2. The unloading operation is presented in Figures 4.8 and 4.9.

![Self-tipping trailer at the beginning of an unloading operation](image)

Figure 4.8: Self-tipping trailer at the beginning of an unloading operation

The cane unloaded from these trailers is used to supplement the feeding of Mill A throughout the day. To move the cane from A1 to the mill table MLTA-1 and a Front-End-Wheel loader is used. The mill table feeding operation by the Front-End-Wheel loader is presented in Figure 4.10. The Front-End-Wheel loader is also used to push-pile the unloaded cane against a steel wall as in the HYDC case in Section 4.2.1 to create more unloading room.

The unloading operation of these trailers is also based on FCFS. After a trailer has been unloaded, it returns to WBA to weigh out and proceed to the field for another cycle.
As reported by Kiteshuo (1991) and Kamau (1991), the smooth operation of this subsystem has been observed to be dependent on the following operational factors:
1. Availability of the Front-End-Wheel loader in the Cane Yard.

2. Hourly milling requirement of Mill A against the hourly basket trailers delivery rate. If the milling requirement is high while the basket trailers delivery is low, more cane is drawn from A1 until the requirement is met. If this is insufficient then cane is drawn from A2.

3. The availability of the unloading space in A1. This can occur if the area A1 is filled up or the Front-End-Wheel loader is unavailable to push-pile the unloaded cane against the steel wall.

From Figures 4.1 and 4.2, the Self-tipping trailers sub-system, can be represented by the queuing situation presented in Figure 4.11. However, from the foregoing description, this sub-system can be represented by both a single-queue, single server and the single queue-multi server (at times multi-server) queuing model. The number of unloading channels available at any given time depends on the available unloading space and the number of Self-tipping trailers that are weighed-in in succession at Weighbridge A (WBA). The sub-system presented in Figure 4.11 is therefore an over simplified version of the actual operational Self-tipping trailers subsystem. During actual operations, the unloading channels at times exceed one.

![Figure 4.11: The Self-tipping trailers sub-system](image-url)
4.2.3 The ordinary bundle trailers - Gantry cranes sub-system

This sub-system consists of single and double bundles trailers and four Gantry cranes. In this sub-system, the unloading operation is based on FCFS like in two sub-system presented in 4.2.1 and 4.2.2. An in-coming trailer weighed through WBA or WBB go for service at any of the unloading points shown in Figures 4.1 and 4.2 provided that the Gantry crane serving that point is fitted with a bridle and is operational. A Gantry crane fitted with a bridle is used for unloading single bundle units, meaning that for a double bundle trailers, the two loads are unloaded separately.

Under normal operating conditions (i.e milling requirements of both mills A and B are met by cane from the basket trailers for mills A and B), all the cane unloaded from these trailers are stock-piled into area A2 which can be sub-divided into A2-1, A2-2, A2-3 and A2-4 as shown in Figure 4.2. This sub-system is known to develop longer and growing queues of cane loaded trailers behind the service points and outside the weighbridges due to the following factors:

1. Mechanical breakdowns of one or more Gantry cranes during milling periods. This results in reduced unloading capacity for the bundle trailers.

2. The fitting of a Gantry crane with a grab to feed the Mill Tables due to low delivery rate of Loose cane by the basket trailers or a breakdown of HYDA or HYDB or both during the first two shifts (i.e between 6.00 and 22.00 hrs)

3. Unmatched available Gantry crane unloading capacity to the number of bundle cane trailers.

From observations made, this sub-system appears to be the most unstable and inefficiently operated. This is supported by the development of long and growing queues and the longer waiting times recorded for the bundle cane trailers. One such queue is presented in Figure 4.12. The trailers shown queuing in Figure 4.12 are already in the Cane Yard and are queuing at one of the four available service points.
Figure 4.12: Queues of bundle cane trailers waiting to unload the bundled cane at one of the Gantry cranes service points

The unloaded cane can be lowered and released into any of the four areas provided that they are empty or the cane already in the stockpile permits such an action. During the unloading process, if the cane from the basket trailers cannot meet the milling requirement, the cane from the bridle-fitted Gantry crane is lowered and released onto the Mill Feed Table to meet the deficit. This is usually done by Gantry cranes GC1 for Mill A and GC4 for Mill B. The cane stockpiled into A2-1 and A2-2 is for feeding Mill A while that in A2-3 and A2-4 is for feeding Mill B. The stockpiled cane from these areas are fed to the mills using the Front-End-Wheel loader and the Gantry crane when fitted with a grab. Mill Table grab feeding is usually carried out by Gantry crane GC1 for Mill A and GC4 for Mill B. This, however, is at times violated if these Gantry cranes are not operational, or are bridle-fitted.
The Gantry cranes are fitted with grabs at night (during the third shift, i.e 22.00 to 6.00 hrs) when the rate of cane inflow for all trailers types is low. This is due to the fact that during this shift, only MSC fleet operate. The Gantry cranes are also fitted with the grabs during rains as this results in no trailers arriving from the fields. The fitting of a Gantry crane with a grab results in a reduced unloading capacity as a grab-fitted Gantry crane cannot be used in unloading operations.

The Ordinary bundle trailer - Gantry crane unloading sub-system can be represented by the queuing situation presented in Figure 4.14. The subsystem may be represented by a multi-queue, multi-channel queuing model (Heinze, 1982). The number of unloading channels although shown as four (4) in Figure 4.14 in reality vary from a minimum of zero (all not operational) to a maximum of 4. These two extremes, however, are rare occurrences.
4.3 Historical Data

Management of Mumias Sugar Company (MSC) collect and keep the following data for their day to day running of the factory:

1. Cane delivery,
2. Waiting time (Cane Yard hourly average waiting time of cane trailers),

4.3.1 Cane delivery

Data on cane delivery was obtained from MSC Transport Section for a period of one year. This sample size was considered adequate for the determination of the cane delivery
parameters required in this study. Cane delivery data was obtained from Transport Section's Hourly Cane Delivery Sheets. To obtain the tonnage of cane delivered by a given trailer type at the end of a given hour from these sheets (except for 07 Hrs), the difference in tonnage recorded between any two successive hours (e.g 08 and 09 hrs) was determined. A sample of the Hourly Cane Delivery Sheet is given in Appendix 1.

Cane delivery for each trailer type is cumulatively recorded in the Hourly Cane Delivery Sheets as delivery process for a day continues. The recording is done cumulatively so that the target set for each trailer type (MSC case) or the contractor is not exceeded. Also the cumulative recording enables one to judge the performance of each trailer type or contractor during the cane delivery period. A day's target may be closed or open depending on:-

1. The amount of cane in the Cane Yard at 6:00 a.m, and
2. The expected factory performance

The hourly cane delivery data collected was stored in a Dbase data file for analysis. Due to the large sample size of the data collected, it was necessary to develop a program that could be used to analyze the data gathered. A dBase program code-named STATS was developed and used to calculate the mean and variance of the cane delivery data. STATS is based on standard equations for calculating the mean and the variance of non-grouped data (Hayslett, 1986). The result obtained for cane delivery are presented in Table 5.15.

The mean hourly cane delivery values for every hour obtained was then stored in a sequential file for later use by the simulation model program. During simulation program execution, the Mean hourly cane deliveries file is opened and the appropriate values are read. The hourly mean cane delivery values read from the sequential file are used in sampling the number of cane trailers arriving at the Cane Yard from the field using the procedure presented in 3.2.2.
4.3.2 Waiting time

Time spent in the Cane Yard, called the waiting time by MSC management, is the sum of time spent in the service queue, time spent in service (unloading time) and the time spent by a trailer between the service point and the weighbridge. The waiting time data was also obtained from the Transport Section's Waiting Time Sheets for a period of one year and stored in a dBase data file for analysis. Waiting times of units using weighbridge A are recorded separately from those using weighbridge B. A sample of such a sheet is shown in Appendix 2.

Using STATS, the mean and variance of the waiting time for all trailer types was determined. The mean waiting time values were used to compare the agreement between the simulated waiting time and the real waiting times (see Section 3.3.1). The results are presented in Table 5.14 in the column under $\mu$. To test the agreement between the simulated and real data, a t-test with $\alpha = 0.05$ was carried out (Steel and Torrie, 1987).

4.3.3 Milling rates

Cane flow rate in the Cane Yard is directly dependent on the milling rate. Hence, if both Mills A and B mill at a higher rate, then the cane flow rate through the Cane Yard is high and vice versa. Milling rates data was obtained from MSC factory laboratory. Milling rate values for both mills was collected for a period of six months of operation (such a sample size was considered adequate for estimation of the probability distribution of the milling rates). The data collected was stored in a dBase data file for statistical analysis.

In order to obtain the frequency distribution for such a large sample size, another dBase program code-named FREQANA was developed. FREQANA is a general purpose dBase program that returns the frequency values for a given class interval of a selected numeric field of a Dbase data file. Besides returning the frequency values for any given range, FREQANA also returns the relative and cumulative frequency values of the selected field. The
frequency, relative frequency and cumulative frequency values are stored in a dBase data file at the end of the program execution. The mean and variance of the milling rates was determined using STATS. The cumulative frequency values obtained for the two mills are given in Table 5.6. A listing of FREQANA is presented in Appendix 3.

The results presented in Table 5.6 were stored in a sequential file for use by the simulation model program. Sampling of the milling rates was carried out by doing a table-search (Section 3.1.2: rectangular approximations). This was accomplished by comparing the value of the random number assigned to a particular mill with the cumulative frequency value. This involved searching the milling rates sequential file until a given condition was met. The mid-value for the class interval corresponding to the random number assigned to either Mill A or B was returned. Two different random numbers were assigned to each mill at the beginning of an hour during the simulation model program execution. This is because the two mills operate independently.

4.4 Fresh Data Collected

All the input data that was required to achieve the objectives of this study was not available from the MSC's archives. The data that was not available was:-

1. Data from which the arrival pattern of units from the field could be deduced from.
2. Data from which the services time pattern (distribution) could be derived from.

To get an idea as to which distributions could be used to sample the number of arriving cane loaded trailers and the service (unloading) times from, data on inter-arrival and service times was collected.
4.4.1 Inter-arrival time

The inter-arrival times data was collected for both loose and bundled cane units as they arrived from the fields. Because of the seemingly random nature of loose and bundled cane unit arrivals, it was considered reasonable to assume that no difference existed between inter-arrival times of the Loose and Bundle cane units. Thus, the sample of the inter-arrival time data gathered was for both trailer types.

As a cane loaded trailer arrived from the field, its arrival time was recorded. The arrival time recorded was the actual time of the day (e.g. 11.38, 11.40, etc) when a cane loaded trailer arrived (passed a specific point towards the weighbridges). The inter-arrival time was taken as the difference in time between any two successive arrivals. When more than one unit arrived at the same time (either a double stack or two tractors towing a single stack trailer), the same arrival time was recorded twice (e.g. 12:02, 12:02). The arrival times data collected was converted to inter-arrival times. This data was stored in a dBase data file for analysis.

The analysis was aimed at determining the frequency distribution of the inter-arrival times. To obtain the frequency distribution of trailers inter-arrival time, suitable class interval were selected and frequency values for the various class intervals determined using FREQANA. The mean and variance was determined using STATS. The results obtained are presented in Table 5.1. The table also gives the lay-out of the output file obtained after execution of FREQANA on any numerical field of a Dbase data file.

From the results obtained, it was assumed (due to the general shape of the inter-arrival time frequency distribution) that the inter-arrival times data came from the exponential distribution. To test the validity of this assumption, a goodness-of-fit test using the Chi-square, $\chi^2$, was performed at a 5% significant level (Ang and Tang, 1975 and Steel and Torrie, 1987). Results of the $\chi^2$-test are presented in Table 5.2 and Figure 5.1.
4.4.2 Cane Yard equipment service times

Unloading (service) times data for all cane unloading equipment was collected for a period of 60 days. For each shift, data was collected for a period of 20 days. Data collection was based on the three sub-systems identified in Sections 4.2.1 to 4.2.3.

Hydro-Loaders service times

Unloading times were collected from all the three Hydro-Loaders. A stop watch was used to carry out the service time timings. Timing of a unit in service was started soon after the unit had become stationary (ready to be unloaded) at the serving point. Timing was stopped when the unloaded trailer started to leave the service point. The timings were carried out for single stacks. For a double basket (bin) trailer, the unloading of the two bins were timed separately. The service times data collected was keyed and stored in a Dbase data file for analysis.

The determination of the Hydro-Loaders service times frequency distribution was done using FREQANA while STATS was used to calculate the sample mean and variance. From the resulting frequency distribution shape, the data was assumed to come from the exponential distribution. A similar approach to that of Section 4.4.1 was used to determine the validity of the above assumption. The results are presented in Table 5.3 and Figure 5.2.

Gantry cranes service time

Service times were determined using a stop watch as in the case of basket trailers above. Timing was carried out for single bundles. For double bundle trailers, each bundle was timed separately. The service time included the time to load back the chains on to the trailer (bundles of cane are tied with two chains).
During the service time data collection, the number of Gantry cranes used in unloading was observed to vary. To account for these variations in the model, the number of Gantry cranes involved in unloading during a given hour was also recorded. This number was observed to vary due to:

1. Mechanical or electrical break downs,
2. Fitting of cranes with Grab feeders (a Grab-fitted Gantry crane cannot be used in unloading).

The data collected was stored in a dBase data file for analysis. FREQANA was used to determine the frequency distribution for both the service times and the number of Gantry cranes employed in unloading the trailers while STATS was used to determine the mean and variance. The service time data distribution was assumed to follow the exponential distribution. A \( \chi^2 \) goodness-of-fit test was performed at 5% significant level to determine the fit. The results of the service time frequency distribution are presented in Table 5.4 and Figure 5.3. The results of the number of operational Gantry cranes (cumulative frequency) was put in a sequential file and a table search operation performed to sample the number of Gantry cranes employed in unloading operation during simulation program execution.

**Self-tipping trailers service time**

Service time timings were started as soon as the trailer had stationed itself at a place where it could unload. Like the ordinary bundle trailers service times, the service times for these trailers also included the time it took to load back the chains. Timing was stopped when an unloaded trailer started its journey back to the weighbridge.

The data collected was stored in a dBase data file and FREQANA and STATS used to determine the frequency distribution and the mean and variance like in the previous cases. From the resulting frequency distribution shape the Self-tipping trailers service time was assumed to come from the exponential distribution. \( \chi^2 \) goodness-of-fit test was performed to at 5% significance level. Results of the analysis are presented in Table 5.5 and Figure 5.4.
4.5 Determination of Cane Yard Stockpiling Capacity

In order to determine the maximum available cane stockpiling capacity, the dimensions of areas A1, A2, and A3 were measured using a tape measure. From the measured dimensions, the floor areas of the stockpiling areas were determined. This was followed by the determination of the maximum heights to which cane could be stockpiled in these areas.

For the areas A1 and A3, the maximum heights were taken as the maximum height of the lower arm of the Front-End-Wheel loader. The maximum height in A2 was taken as the maximum distance from the ground to the tip of a Bridle-fitted Gantry crane less the average diameter of one bundle.

From the various areas’ maximum height determinations and the floor area calculations, the volume of cane that each area could handle was estimated using the density-mass-volume relationship given below as,

\[ \rho = \frac{m}{v} \]  \hspace{1cm} \ldots (4.1)

where

- \( \rho \) = density of the material, kg/m³
- \( v \) = volume, m³
- \( m \) = mass, kg.

According to Kamau (1991), research work on piled cane density determination by MSC’s Research and Development section established that the average density of stockpiled cane in the MSC sugar zone is 340 kg/m³. This value was used to determine the mass of cane that could be stockpiled in the Cane Yard stockpiling areas.
4.6 Cane Yard Simulation Model Development

4.6.1 Mathematical model

Notations used in developing the mathematical model are given in the List of Abbreviations section. Equations for sampling cane arrivals and service time are based on the assumption that the inter-arrival time and service times are from the exponential distribution. The inverse transform method is used to sample arrival and the service times. The following equations were developed for the Cane Yard operations:

1. Cane Deliveries
   (a) Loose cane deliveries (arrivals) through WBA

   \[ T_{ABK} = \left( \frac{-1}{abk} \right) \times \ln(R_u) \]  \hspace{1cm} \ldots (4.2)

   (b) Loose cane deliveries (arrivals) through WBB

   \[ T_{BBK} = \left( \frac{-1}{bbk} \right) \times \ln(R_u) \]  \hspace{1cm} \ldots (4.3)

   (c) Bundle cane deliveries through WBA and WBB

   \[ T_{BD} = \left( \frac{-1}{abbd} \right) \times \ln(R_u) \]  \hspace{1cm} \ldots (4.4)

2. Service (unloading) times
   (a) HYDA service time

   \[ T_{HYDA} = \left( \frac{-1}{m_{hyda}} \right) \times \ln(R_u) \]  \hspace{1cm} \ldots (4.5)

   (b) HYDB service times

   \[ T_{HYDB} = \left( \frac{-1}{m_{hydb}} \right) \times \ln(R_{ubu}) \]  \hspace{1cm} \ldots (4.6)
(c) Gantry cranes service times

\[ T_{GC} = \left( \frac{-1}{MGCU} \right) \ln(R_u) \]  \hspace{1cm} \ldots (4.7)

(d) Self-tipping trailers

\[ T_{ST} = \left( \frac{-1}{MSTU} \right) \ln(R_u) \]  \hspace{1cm} \ldots (4.8)

where

\[ R_u = \text{a uniformly distributed \([0, 1]\) random number.} \]


(a) Feeding mills A and B from the basket trailers

\[ MillA = MillA - PLBK \]
\[ MillB = MillB - PLBK \]  \hspace{1cm} \ldots (4.9)

(b) Mill A feeding from the Self-tipping trailers stock

\[ MillA = MillA - STSTOCK \]  \hspace{1cm} \ldots (4.10)

(c) Mills feeding from Gantry cranes stockpile. Several possibilities may arise:

\[ MillA = 0 \]
\[ MillB = 0 \]  \hspace{1cm} \ldots (4.11)

\[ GCSTOCK = GCSTOCK - MillAB \]

Equation (4.11) arises when the milling requirements for both mills are satisfied.

\[ MillB = 0 \]
\[ MillA = MillAB - GCSTOCK \]  \hspace{1cm} \ldots (4.12)

\[ GCSTOCK = 0 \]

Equation (4.12) arises when the milling requirement for Mills A and B cannot all be met but Mill B has a milling requirement that is greater than milling requirement for Mill A but less...
(c) Gantry cranes service times

\[ TGC = \left( -\frac{1}{MGCU} \right) \cdot \ln(R_u) \] \hspace{1cm} (4.7)

(d) Self-tipping trailers

\[ TST = \left( -\frac{1}{MSTU} \right) \cdot \ln(R_u) \] \hspace{1cm} (4.8)

where

\[ R_u = \text{a uniformly distributed } [0, 1] \text{ random number.} \]


(a) Feeding mills A and B from the basket trailers

\[ \text{Mill}_A = \text{Mill}_A - \text{PLBK} \] \hspace{1cm} (4.9)

\[ \text{Mill}_B = \text{Mill}_B - \text{PLBK} \]

(b) Mill A feeding from the Self-tipping trailers stock

\[ \text{Mill}_A = \text{Mill}_A - \text{STSTOCK} \] \hspace{1cm} (4.10)

(c) Mills feeding from Gantry cranes stockpile. Several possibilities may arise:

\[ \text{Mill}_A = 0 \]

\[ \text{Mill}_B = 0 \] \hspace{1cm} (4.11)

\[ GCSTOCK = GCSTOCK - \text{Mill}_AB \]

Equation (4.11) arises when the milling requirements for both mills are satisfied.

\[ \text{Mill}_B = 0 \]

\[ \text{Mill}_A = \text{Mill}_AB - GCSTOCK \] \hspace{1cm} (4.12)

\[ GCSTOCK = 0 \]

Equation (4.12) arises when the milling requirement for Mills A and B cannot all be met but Mill B has a milling requirement that is greater than milling requirement for Mill A but less
than or equal to the total cane stock available under the Gantry cranes

\[ \text{MillA} = 0 \]

\[ \text{MillB} = \text{MillAB} - \text{GCSTOCK} \quad \ldots (4.13) \]

\[ \text{GCSTOCK} = 0 \]

Explanation for Equation (4.13) is similar to that for Equation (4.12) above.

4. Average waiting times

(a) When all units in a queue at the start of the hour for a particular unloading equipment are unloaded by the end of that hour the following equation is used to estimate the average waiting time.

\[ \bar{W} = \frac{T_1 + (T_1 + T_2) + \ldots + (T_1 + T_2 + \ldots + T_n)}{n} \quad \ldots (4.14) \]

where

\[ T_1 = \text{service time of } \text{ith} \text{ unit (one stack).} \]

\[ n = \text{number of units at the beginning of the hour.} \]

(b) When all the units waiting to be unloaded by a particular unloading equipment cannot be unloaded, the following equation can be used to estimate the average waiting time

\[ \bar{W} = \frac{T_1 + (T_1 + T_2) + \ldots + (T_1 + T_2 + \ldots + T_{n-1} + T_{n_2}) + n_2}{N} \quad \ldots (4.15) \]

where

\[ n_1 = \text{number of units at the end of the hour} \]

\[ n_2 = \text{number of units not unloaded by the end of the hour} \]

\[ N = n_1 + n_2 \]
4.6.2 Flow charts construction

In order to convert the mathematical model (equations) developed into a computer program, flow charts describing the Cane Yard operations were constructed. Flow charts construction was based on the activities (operations) of the Cane Yard. The flow charts constructed are presented in Appendix 4. The flow charts constructed were for the following:

1. **Hydro-Loaders - Loose cane subsystem**: The flow chart components of this subsystem are:

   (a) Loose cane delivery. This is similar for both weighbridges,
   (b) Loose cane unloading operations for Hydro-Loaders, and
   (c) Milling activity for both mills.

2. **Self-tipping trailers subsystem**: This consisted of the following:

   (a) Delivery of Bundled cane by the Self-tipping trailers,
   (b) Self-tipping trailers unloading operation, and
   (c) Mill A feeding operation by the Front-End-Wheel loader with cane from the area A1,

3. **Gantry cranes - Bundle cane trailers subsystem**: This has the following components:

   (a) Delivery of Bundle cane,
   (b) Generation of the number of operational Gantry cranes,
   (c) Unloading operation of the ordinary Bundle cane trailers, and
   (d) Mills feeding operation the Gantry cranes either bridle or grab fitted with cane from area A2.

After constructing the above flow charts, a computer program was developed using Turbo PASCAL Version 5.5.
4.6.3 Computer simulation program

Development of the simulation program was based on the flow charts that were developed in Section 4.6.2 above. The main program developed in Turbo PASCAL was used to call the procedures or sub-programs developed for various parts of the flow charts. The following procedures were developed:

1. **Procedure Random Number Generator (RNG)** - this is a procedure that generates the random numbers required by other procedures during program execution.

2. **Procedure Delivery** - this is a procedure that samples the arrival of cane loaded trailers at the beginning of the hour using the equations derived in Section 4.6.1.

3. **Procedure Initialize** - this is a procedure that updates the stock levels and number of various unit types.

4. **Procedure Milling** - a procedure that uses random numbers to return the milling rate values for Mill A and Mill B at the start of every hour.

5. **Procedure Generated Initial Values (GenorValues)** - a procedure that returns the number of units awaiting unloading at the start of every hour.

6. **Procedure Loose Cane Unloading by HYDA (LCUnloadingA)** - a procedure that simulates the unloading of Loose cane units to Mill A Feed Table by HYDA. It also simulates the waiting times of loose cane trailers unloaded by HYDA.

7. **Procedure Self-tipping Trailers Unloading (STUnloading)** - a procedure that simulates the unloading of Self-tipping trailers in area A2 and calculates the hourly average waiting times.

8. **Procedure Loose Cane Unloading by HYDB (LCUnloadingB)** - a procedure that simulates the unloading of Loose cane units on to Mill B Feed Table by HYDB. It also simulates the waiting times of loose cane trailers unloaded by HYDB.
9. **Procedure Number of Operational Gantry Cranes** (NumberOfWorkingGCS) - a procedure that returns the number of Gantry cranes employed to unload the double and single Bundle units.

10. **Procedure Stockpiling** - a procedure that simulates the stockpiling of cane by the Gantry cranes.

11. **Procedure Stockpile Mill Feeding (STPFeeding)** - a procedure that simulates the feeding of mills from the stockpiled cane under the Gantry crane area, A2.

12. **Procedure Total-Stock** - a procedure that updates the stock level at the end of every hour. Total stock comprises of cane from the Self-tipping trailers and Gantry cranes stockpiling areas.

13. **Procedure Trucks Update (TRUCKSUPDATE)** - a procedure that updates the number of units that were not unloaded and puts them back into their respective queues for next hour's unloading.

14. **Procedure Print Heading (PRINTHEAD)** - a procedure that prints the heading of the selected output report after every 24 hours of factory operation.

15. **Procedure Print-Out (PRINTOUT1)** - a procedure that prints out the selected output values from the simulation model.

### 4.6.4 Computer program Verification and Validation

According to Jørgensen (1986), verification may be defined as the *internal logic* of a model and was performed for each procedure (module) developed. Verification was performed using the debugging tools of Turbo PASCAL. The main debugging tools used were *trace* and *step* facilities. After verifying that a procedure behaved as was intended, the procedure was included in the *main program*. All procedures were tested in this manner and merged to produce the Cane Yard simulation model program.
After verification, the model was validated (using the approach presented in Section 3.3.1) by comparing the simulated data with the real (historical) data. Validation tests were performed statistically at 5% significance level for the following:

1. Milling rates for both mills,
2. Cane delivery for selected hours,
3. Average waiting times.

Where comparisons involved frequency distributions, FREQANA was used to determine the frequency distribution followed by a Chi-square, $\chi^2$, goodness-of-fit test (Ang and Tang, 1975). For comparison of mean values (e.g. mean hourly cane units arrival rates for a selected hour), a hypothesis testing based on no difference between the means of simulated and historical data was performed (Steel and Torrie, 1987). Validation results are presented in Section 5.2.

4.7 Simulation Experiments

Simulation experiments were designed to answer the managerial questions contained in Chapter 1. Relevant input variables and parameters were altered and their effect on the performance of the Cane Yard operations were analyzed statistically. The experiments were designed to answer "what-if" questions. The experiments were designed to analyze the following:

1. The effect of increasing the number of working Gantry cranes at any hour of operation to three throughout on average waiting time of the Bundle cane units. A sensitivity analysis was carried out to see whether the waiting times are different from the actual waiting times obtained when the model is operating under normal conditions.
2. The effect of decreasing the average hourly arrival rate of Bundle cane units and increasing by the same amount the number of average hourly arrival rate
of Loose cane units on the waiting times of the various unit (trailer) types. The arrival of Loose cane units increment through weighbridges A and B were increased by equal amounts in this case.

3. Possibility of parking all the transport units by 22.00 hours so that cane transport is carried out using only Two Shifts of eight hours each. To ensure that the daily mill requirements are met, all the cane delivered to the yard during the third shift must be delivered during the 16 hours of cane delivery.

4.8 Analyzing the Simulation Experiments

Simulation experiments were designed to compare the alternative courses of action that could be taken to improve the general flow of cane within the MSC Cane Yard. For each simulation experiment performed, data was collected and statistically analyzed to judge the effect of altering the operating system's set up on the Cane Yard performance measures.

The statistical analysis approach employed depended on the nature of the experimental design (i.e the number of input variables altered). Where the analysis involved comparing the Cane Yard performance measures obtained from the model when under normal operating conditions and when the model is operating after altering a single input parameter, a statistical analysis using a t-test based on the principle of comparison of two independent samples with equal variance at 5 percent confidence level (Steel and Torrie, 1987) was performed.

In a situation when an input factor was operated at various levels, a statistical analysis using the Analysis of variance method (ANOVA) was performed at 5% confidence level. The data analyzed was for a period of 24 days for each experiment.
CHAPTER 5: RESULTS, ANALYSIS AND DISCUSSION

5.1 Historical and New Data Analysis

The data collected was statistically analyzed to determine the frequency distributions and parameters needed by the simulation computer program designed for the Cane Yard operations.

5.1.1 Inter-arrival time of trucks

The frequency distribution for the inter-arrival times are presented in Table 5.1. Frequency distribution was determined using FREQANA. The mean and variance was calculated using STATS. The results obtained after using STATS are presented in the last two rows of Table 5.1

Table 5.1: Results of inter-arrival times data obtained after running FREQANA and STATS

<table>
<thead>
<tr>
<th>Lclass*</th>
<th>Uclass*</th>
<th>Frequency*</th>
<th>RFrequency*</th>
<th>CumFrequency*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>44</td>
<td>0.314</td>
<td>0.314</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>30</td>
<td>0.214</td>
<td>0.528</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>19</td>
<td>0.136</td>
<td>0.664</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>7</td>
<td>0.050</td>
<td>0.714</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>11</td>
<td>0.079</td>
<td>0.793</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
<td>0.043</td>
<td>0.836</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>7</td>
<td>0.050</td>
<td>0.886</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>6</td>
<td>0.043</td>
<td>0.929</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>6</td>
<td>0.043</td>
<td>0.972</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>4</td>
<td>0.029</td>
<td>1.001</td>
</tr>
</tbody>
</table>

Total 140 1.001

Mean 3.15
Variance 12.92

The terms with asterisk in Table 5.1 are:
- Lclass - lower class limit
- Uclass - upper class limit
- RFrequency - relative frequency
- CumFrequency - cumulative frequency

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From the results presented in Table 5.1, the inter-arrival time data was assumed to come from the negative exponential distribution. Using Equation (3.3), the cell probabilities (chosen time interval) were determined. The theoretical cell frequencies were then calculated as the product of the cell probabilities and the sample size (in this case 140).

In order to determine the degree of fit between the observed and the expected cell frequencies (for the assumed exponential distribution), $\chi^2$-goodness-of-fit test was performed at 5% significance level. The results are presented in Table 5.2 and Figure 5.1.

Table 5.2: Observed and theoretical frequencies of the trailers inter-arrival times

<table>
<thead>
<tr>
<th>Time Interval (min.)</th>
<th>Probability</th>
<th>Observed Freq.(OF)</th>
<th>Expected Freq.(EF)</th>
<th>(OB-EF)$^2$/EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq t &lt; 1$</td>
<td>0.272</td>
<td>44</td>
<td>38.1</td>
<td>0.914</td>
</tr>
<tr>
<td>$1 \leq t &lt; 2$</td>
<td>0.198</td>
<td>30</td>
<td>27.7</td>
<td>0.191</td>
</tr>
<tr>
<td>$2 \leq t &lt; 3$</td>
<td>0.144</td>
<td>19</td>
<td>20.2</td>
<td>0.071</td>
</tr>
<tr>
<td>$3 \leq t &lt; 4$</td>
<td>0.105</td>
<td>7</td>
<td>14.7</td>
<td>4.033</td>
</tr>
<tr>
<td>$4 \leq t &lt; 5$</td>
<td>0.077</td>
<td>11</td>
<td>10.8</td>
<td>0.004</td>
</tr>
<tr>
<td>$5 \leq t &lt; 6$</td>
<td>0.055</td>
<td>6</td>
<td>7.7</td>
<td>0.375</td>
</tr>
<tr>
<td>$6 \leq t &lt; 8$</td>
<td>0.070</td>
<td>7</td>
<td>9.8</td>
<td>0.800</td>
</tr>
<tr>
<td>$8 \leq t &lt; 10$</td>
<td>0.037</td>
<td>6</td>
<td>6.2</td>
<td>0.123</td>
</tr>
<tr>
<td>$10 \leq t &lt; 12$</td>
<td>0.020</td>
<td>6</td>
<td>2.8</td>
<td>3.357</td>
</tr>
<tr>
<td>$12 \leq t &lt; 20$</td>
<td>0.022</td>
<td>4</td>
<td>3.1</td>
<td>0.261</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1.000</td>
<td>140</td>
<td>140.1</td>
<td>10.429</td>
</tr>
</tbody>
</table>

Chi-square$_{calc}$ = $\Sigma$ (OF-EF)$^2$/EF = 10.429.

Chi-square$_{crit}$ = 15.5 at $\alpha=0.05$.

Conclusion: There is no statistical evidence to suggest that the negative exponential distribution does not provide an adequate fit for the trailers inter-arrival time. The assumption that the inter-arrival times data follow the exponential distribution is therefore acceptable.
From Table 5.2, the $\chi^2$-contribution for the time intervals 3-4 and 10-12 contribute more than 73% to the final $\chi^2$ value. This can be attributed to the small sample size that was used in testing the assumption that the inter-arrival times data come from an exponential distribution. For the purposes of this study, however, the analysis established that the inter-arrival times for cane trailers follow the exponential distribution.

Since the inter-arrival time distribution fit the exponential distribution, the number of units (cane stacks) arriving at the yard for unloading within any specified time interval, $\tau$, follow a Poisson distribution. The proof of this relationship was presented in Section 3.2.1. Thus in simulating the arrivals the approach of Section 3.2.2 was used.
5.1.2 Cane Yard equipment unloading times distribution

Hydro-Loaders

Using the data collected and after running the program FREQANA to obtain the frequency values for selected time intervals, a cumulative distribution equation that approximately fitted the collected data to a negative exponential curve was derived. The derived cumulative distribution equation for the offloading data is

\[ F(t) = 1 - e^{-0.459t} \]  \hspace{1cm} \ldots (5.1) \]

where

\[ t = \text{time in minutes} \]
\[ F(t) = \text{cumulative distribution function} \]

Using Equation (5.1), the expected cell frequencies were calculated. \textit{Chi-square goodness-of-fit} test was performed at 5% confidence level to establish whether the service time data fitted Equation (5.1). Table 5.3 shows the results obtained after carrying out the above enumerated procedures.

<table>
<thead>
<tr>
<th>Time interval (Minutes)</th>
<th>Observed Frequency (OF)</th>
<th>Expected Frequency (EF)</th>
<th>(OF - EF)/EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt;= t &lt; 5</td>
<td>1771</td>
<td>1766.9</td>
<td>0.010</td>
</tr>
<tr>
<td>5 &lt;= t &lt; 10</td>
<td>173</td>
<td>178.1</td>
<td>0.140</td>
</tr>
<tr>
<td>10 &lt;= t &lt; 15</td>
<td>13</td>
<td>17.9</td>
<td>1.340</td>
</tr>
<tr>
<td>15 &lt;= t &lt; 20</td>
<td>6</td>
<td>2.0</td>
<td>8.000</td>
</tr>
<tr>
<td>20 &lt;= t &lt; 25</td>
<td>1</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>25 &gt; t</td>
<td>1</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>1965</td>
<td>1964.9</td>
<td>9.490</td>
</tr>
</tbody>
</table>

\[ EF = \text{Expected Frequency}, \ OF = \text{Observed Frequency} \]
Conclusion: There is no statistical evidence to suggest that the Hydro-Loader service time (unloading) data does not fit Equation (5.1) if the tail-end data (i.e. starting from time $t \geq 15$ minutes) is ignored.

The results are not significant at 5% confidence level for the unloading time data within the range of 0 to 15 minutes. This is where the bulk (99.59%) of the unloading time frequencies fall. Thus, it can be stated that the unloading time data for the Hydro-Loaders beyond 15 minutes are unusual occurrences and can be ignored. This is supported by the low number of observations that fall beyond 15 minutes and the fact that they are far from the mean unloading time of 2.15 minutes obtained. Also the Hydro-Loaders have a design unloading rate of 180 tons per hour which cannot be attained if the longer service times observed in Table 5.3 are considered to be normal Hydro-Loader unloading time occurrences.

![Graph](image)

**Figure 5.2:** Fitted and actual service times for the Hydro-Loaders

**Gantry cranes**

A similar treatment as outlined in the analysis of the Hydro-Loaders service time data was employed to analyze the Gantry cranes service time data. An equation that was found to approximate the Gantry cranes unloading time frequency distribution is
The above equation was employed in calculating the expected (theoretical) time interval cell frequencies for the Gantry cranes. The results obtained are presented in Table 5.4 after performing all the statistical analyses.

Table 5.4: Fitted and observed data for the Gantry cranes unloading time

<table>
<thead>
<tr>
<th>Time interval (min.)</th>
<th>Observed Frequency (OF)</th>
<th>Expected Frequency (EF)</th>
<th>(OF - EF)^2/OF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt;= t &lt; 8</td>
<td>820</td>
<td>824.1</td>
<td>0.02</td>
</tr>
<tr>
<td>8 &lt;= t &lt; 12</td>
<td>103</td>
<td>96.7</td>
<td>0.41</td>
</tr>
<tr>
<td>12 &lt;= t &lt; 16</td>
<td>49</td>
<td>39.5</td>
<td>0.28</td>
</tr>
<tr>
<td>16 &lt;= t &lt; 20</td>
<td>10</td>
<td>16.8</td>
<td>2.13</td>
</tr>
<tr>
<td>20 &lt;= t &lt; 24</td>
<td>4</td>
<td>6.9</td>
<td>*</td>
</tr>
<tr>
<td>24 &lt;= t &lt; 28</td>
<td>1</td>
<td>2.0</td>
<td>*</td>
</tr>
<tr>
<td>t &gt;= 28</td>
<td>0</td>
<td>2.0</td>
<td>3.19*</td>
</tr>
<tr>
<td>Total</td>
<td>987</td>
<td>987.1</td>
<td>6.030</td>
</tr>
</tbody>
</table>

3.19* = contribution to Chi-square value of the last three cells (i.e., contribution for \( t < 20 \) to \( t = 28 \) minutes).

OF = Observed frequency
EF = Expected (theoretical) frequency
Chi-square\_critical = 7.81 (with 5-1-1 df and \( \alpha = 0.05 \)).

Conclusion: There is no statistical evidence to suggest that the Gantry cranes unloading time data do not adequately fit the exponential distribution expression given by Equation (5.2).

Self-tipping trailers

Unlike the Hydro-Loaders and the Gantry cranes, fitting of the unloading time data to the exponential distribution for Self-tipping trailers was straightforward. The mean of the sample was determined from the formula

\[
\mu_{estimated} = \frac{\sum f_i X_i}{\sum f_i}
\]

... (5.3)
where

\[ f_i = \text{observed cell frequencies for a given time interval} \]
\[ x_i = \text{mid-point value of the time interval}. \]

Table 5.5 below shows the results obtained after subjecting the unloading time data to the same treatment as for the other unloading Cane Yard equipment.

**Table 5.5: Results of Self-tipping trailers unloading times frequency distribution**

<table>
<thead>
<tr>
<th>Time Interval (min.)</th>
<th>Observed Frequency (OF)</th>
<th>Probability</th>
<th>Expected Frequency (OF)</th>
<th>(OF - EF)^2 / EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt;= t &lt; 8</td>
<td>149</td>
<td>0.681</td>
<td>150.5</td>
<td>0.02</td>
</tr>
<tr>
<td>8 &lt;= t &lt; 12</td>
<td>42</td>
<td>0.139</td>
<td>30.7</td>
<td>4.16</td>
</tr>
<tr>
<td>12 &lt;= t &lt; 16</td>
<td>14</td>
<td>0.078</td>
<td>17.2</td>
<td>0.60</td>
</tr>
<tr>
<td>16 &lt;= t &lt; 20</td>
<td>8</td>
<td>0.045</td>
<td>9.9</td>
<td>0.36</td>
</tr>
<tr>
<td>20 &lt;= t &lt; 24</td>
<td>5</td>
<td>0.025</td>
<td>6.5</td>
<td>*</td>
</tr>
<tr>
<td>24 &lt;= t &lt; 28</td>
<td>2</td>
<td>0.014</td>
<td>3.1</td>
<td>*</td>
</tr>
<tr>
<td>28 &lt;= t &lt; 32</td>
<td>1</td>
<td>0.008</td>
<td>1.8</td>
<td>*</td>
</tr>
<tr>
<td>t &gt;= 32</td>
<td>0</td>
<td>0.010</td>
<td>2.4</td>
<td>1.80*</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>221</strong></td>
<td><strong>1.000</strong></td>
<td><strong>221.1</strong></td>
<td><strong>8.14</strong></td>
</tr>
</tbody>
</table>

Chi-square\_calculated < Chi-square\_critical  
* - combined \( \chi^2 \) contribution for the last four cells  
OF - Observed Frequency  
EF - Expected Frequency

**Conclusion:** There is no statistical evidence to suggest that the Self-tipping trailer service time do not come from a negative exponential distribution. Service time distribution graph for the self tipping trailers is given in Figure 5.4.
Figure 5.3: Fitted and observed service times for the Gantry cranes

Figure 5.4: Fitted and observed service times for the Self-tipping trailers
5.1.3 Milling rates distribution

Milling rates data collected for Mills A and B were observed to range from zero for both mills to a maximum of 185 tonnes per hour for Mill A and 220 tonnes per hour for Mill B. It was also observed that on Mondays and Thursdays, for 8 to 12 hours from 6.00 hours, continuous zero tonnes per hour were recorded as the milling rates for either Mill A or B. The continuous zero milling rate value recorded for such long periods are the milling rate values recorded when a certain mill is under maintenance. These continuous zero milling rate values were deleted from the data file that contained the raw milling rates data before the statistical analysis was carried out. The other zero milling rates, which were scattered in between other milling rate values (non-zero) were considered to be those recorded when a mill had a break down. Upto five (i.e five hours breakdowns) continuous zero value were considered to be non-maintenance zero milling rate values, and was therefore included in the final data analyzed.

The resulting milling rates data were subjected to FREQANA and STATS. FREQANA produced frequency distribution results for equal class interval of 10 tonnes per hour starting with the milling rate of zero and ending with a milling rate of 215 tonnes per hour. From the FREQANA output sheet, the results presented in Table 5.6 were extracted for both Mills A and B. The average milling rates for both mills was determined using STATS. A value of 107 tonnes per hour was returned for Mill A while Mill B had an average milling rate of 139 tonnes per hour. The data gathered was for a period of 6 months, the sample size being 4120 for both mills.

After obtaining the milling rates frequency distribution results for both mills A and B for the chosen class intervals, graphs of the mid-class value (for a given class interval) against the corresponding frequencies were plotted. The resulting graphs are given by Figures 5.5 and 5.6. The milling rate frequency distributions obtained for both mills have a similar general shape, but do not appear to fit any known frequency distribution.
Table 5.6: Milling rates frequency distribution after subjecting the milling rates data to FREQANA

<table>
<thead>
<tr>
<th>Mill rate (ton/hr)</th>
<th>Mill A Frequency</th>
<th>CF(A)</th>
<th>Mill B Frequency</th>
<th>CF(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>244</td>
<td>0.059</td>
<td>191</td>
<td>0.046</td>
</tr>
<tr>
<td>5.5</td>
<td>6</td>
<td>0.060</td>
<td>6</td>
<td>0.047</td>
</tr>
<tr>
<td>15.0</td>
<td>29</td>
<td>0.067</td>
<td>19</td>
<td>0.052</td>
</tr>
<tr>
<td>25.0</td>
<td>49</td>
<td>0.079</td>
<td>23</td>
<td>0.058</td>
</tr>
<tr>
<td>35.0</td>
<td>48</td>
<td>0.091</td>
<td>27</td>
<td>0.065</td>
</tr>
<tr>
<td>45.0</td>
<td>59</td>
<td>0.105</td>
<td>24</td>
<td>0.071</td>
</tr>
<tr>
<td>55.0</td>
<td>57</td>
<td>0.119</td>
<td>29</td>
<td>0.078</td>
</tr>
<tr>
<td>65.0</td>
<td>95</td>
<td>0.142</td>
<td>41</td>
<td>0.088</td>
</tr>
<tr>
<td>75.0</td>
<td>99</td>
<td>0.166</td>
<td>49</td>
<td>0.100</td>
</tr>
<tr>
<td>85.0</td>
<td>155</td>
<td>0.204</td>
<td>44</td>
<td>0.111</td>
</tr>
<tr>
<td>95.0</td>
<td>197</td>
<td>0.252</td>
<td>51</td>
<td>0.123</td>
</tr>
<tr>
<td>105.0</td>
<td>313</td>
<td>0.328</td>
<td>79</td>
<td>0.142</td>
</tr>
<tr>
<td>115.0</td>
<td>469</td>
<td>0.442</td>
<td>91</td>
<td>0.164</td>
</tr>
<tr>
<td>125.0</td>
<td>640</td>
<td>0.597</td>
<td>167</td>
<td>0.205</td>
</tr>
<tr>
<td>135.0</td>
<td>668</td>
<td>0.759</td>
<td>273</td>
<td>0.271</td>
</tr>
<tr>
<td>145.0</td>
<td>528</td>
<td>0.887</td>
<td>428</td>
<td>0.375</td>
</tr>
<tr>
<td>155.0</td>
<td>310</td>
<td>0.962</td>
<td>671</td>
<td>0.538</td>
</tr>
<tr>
<td>165.0</td>
<td>110</td>
<td>0.989</td>
<td>733</td>
<td>0.716</td>
</tr>
<tr>
<td>175.0</td>
<td>31</td>
<td>0.997</td>
<td>606</td>
<td>0.863</td>
</tr>
<tr>
<td>185.0</td>
<td>12</td>
<td>1.000</td>
<td>319</td>
<td>0.941</td>
</tr>
<tr>
<td>195.0</td>
<td>0</td>
<td>1.000</td>
<td>176</td>
<td>0.984</td>
</tr>
<tr>
<td>205.0</td>
<td>0</td>
<td>1.000</td>
<td>56</td>
<td>0.998</td>
</tr>
<tr>
<td>215.0</td>
<td>0</td>
<td>1.000</td>
<td>10</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The terms used in the above table are:

- **CFA** - Cumulative frequency value for a given milling rate class interval for Mill A obtained after running FREQANA on Mill A milling rates raw data.
- **CFB** - Cumulative frequency value for a given milling rate class interval for Mill B obtained after running FREQANA on Mill B milling rates raw data.

Attempts were made to fit the resulting milling rates frequency distributions for mills A and B to any known standard probability distribution but this was unsuccessful. Further attempts were made to derive an equation an equation that could approximate the milling rate frequency distribution (like in the case of the Hydro-Loaders and Gantry cranes service time distributions) but this was also unsuccessful. With this the hope of using an equation to sample the milling rates was abandoned.
Since the milling rate is one of the major Cane Yard simulation computer program inputs, frequency distribution tables based on the cumulative frequencies presented in Table 5.6 for Mills A and B were used to sample the hourly milling rates for Mills A and B by carrying
out a table-search. 

This was done by first picking two random numbers from the random numbers array (generated by rng procedure) and by comparing the random number assigned to a given mill against the cumulative frequency of that mill, a certain mid-value milling rate for the mill was returned.

5.2 Validation of the Cane Yard Simulation Model

A listing of the computer simulation program developed is presented in Appendix 3 together with those of FREQANA and STATS, the two dBase general purpose programs which were extensively used in analyzing the input (raw) data. The model is validated by comparing the selected real and simulated Cane Yard performance measures for similar operating conditions. The performance measures selected for validating the model are the milling rates, the waiting times and the cane deliveries for selected hours.

5.2.1 Milling rates

To decide on whether or not the model developed is capable of simulating acceptable milling rates (hourly) for both mills, a sample size of 4120 was considered. This simulated milling rate sample size was equal in size to the real milling rates sample size used in determining the frequency distribution of the actual milling rates. Simulated milling rates frequency distributions were established using FREQANA. The resulting frequencies obtained were then treated as the observed milling rates frequency while the frequency distribution of the actual milling rates were taken as the expected (theoretical) frequencies.

In order to establish how well the simulated milling rates compared with their real world (operational) counterparts, Chi-square goodness-of-fit test was preformed at 5% confidence level. The results obtained are presented in Tables 5.7 and 5.8, and from these tables, it can be seen that at 5% confidence level, there is no statistical evidence to suggest that the two
samples (simulated and actual milling rates for both mills) do not come from the same population.

Figures 5.7 and 5.8 are based on actual and simulated frequency values from Tables 5.7 and 5.8. These show the degree of fit between the simulated and actual milling rates for Mills A and B. The figures show that in general, the simulated and actual milling rates for Mills A and B fit comparably well.

Table 5.7: Simulated and actual milling rates frequency distribution for Mill A

<table>
<thead>
<tr>
<th>MID-CLASS</th>
<th>ACTUAL-A</th>
<th>SIMUL-A</th>
<th>Contribution to Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>244</td>
<td>241</td>
<td>0.037</td>
</tr>
<tr>
<td>5.5</td>
<td>6</td>
<td>4</td>
<td>*</td>
</tr>
<tr>
<td>15.0</td>
<td>29</td>
<td>26</td>
<td>0.714*</td>
</tr>
<tr>
<td>25.0</td>
<td>49</td>
<td>58</td>
<td>1.653</td>
</tr>
<tr>
<td>35.0</td>
<td>48</td>
<td>54</td>
<td>0.750</td>
</tr>
<tr>
<td>45.0</td>
<td>59</td>
<td>53</td>
<td>0.610</td>
</tr>
<tr>
<td>55.0</td>
<td>57</td>
<td>60</td>
<td>0.158</td>
</tr>
<tr>
<td>65.0</td>
<td>95</td>
<td>82</td>
<td>1.779</td>
</tr>
<tr>
<td>75.0</td>
<td>99</td>
<td>95</td>
<td>0.162</td>
</tr>
<tr>
<td>85.0</td>
<td>155</td>
<td>157</td>
<td>0.026</td>
</tr>
<tr>
<td>95.0</td>
<td>197</td>
<td>191</td>
<td>0.183</td>
</tr>
<tr>
<td>105.0</td>
<td>313</td>
<td>305</td>
<td>0.205</td>
</tr>
<tr>
<td>115.0</td>
<td>469</td>
<td>477</td>
<td>0.135</td>
</tr>
<tr>
<td>125.0</td>
<td>640</td>
<td>641</td>
<td>0.002</td>
</tr>
<tr>
<td>135.0</td>
<td>668</td>
<td>673</td>
<td>0.037</td>
</tr>
<tr>
<td>145.0</td>
<td>528</td>
<td>516</td>
<td>0.273</td>
</tr>
<tr>
<td>155.0</td>
<td>310</td>
<td>315</td>
<td>0.081</td>
</tr>
<tr>
<td>165.0</td>
<td>110</td>
<td>118</td>
<td>0.582</td>
</tr>
<tr>
<td>175.0</td>
<td>31</td>
<td>38</td>
<td>0.581</td>
</tr>
<tr>
<td>185.0</td>
<td>12</td>
<td>13</td>
<td>0.083</td>
</tr>
<tr>
<td>195.0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>205.0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>215.0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

Total 4119 4117 8.051

* Chi-square contribution for combined classes.

ACTUAL-A = Actual Mill A milling rate data collected from the MSC factory laboratory

SIMUL-A = Simulated Mill A milling rate values obtained after running the simulation computer program for a period of six months.

Conclusion: There is no statistical evidence to suggest that the simulated and the actual milling rates data for mill A come from two different populations.
Therefore, the simulated milling rates frequency distribution, within the acceptable limits, fit the actual milling rates frequency distribution for the chosen class intervals for Mill A under normal operating condition. This implies that the Milling Procedure is capable of generating acceptable milling rate values for Mill A.

Table 5.8: Simulated and actual milling rates frequency distribution for Mill B

<table>
<thead>
<tr>
<th>MID-CLASS</th>
<th>ACTUAL-B</th>
<th>SIMUL-B</th>
<th>Contribution to Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>191</td>
<td>199</td>
<td>0.335</td>
</tr>
<tr>
<td>5.5</td>
<td>6</td>
<td>7</td>
<td>0.167</td>
</tr>
<tr>
<td>15.0</td>
<td>19</td>
<td>18</td>
<td>0.053</td>
</tr>
<tr>
<td>25.0</td>
<td>23</td>
<td>27</td>
<td>0.696</td>
</tr>
<tr>
<td>35.0</td>
<td>27</td>
<td>32</td>
<td>0.926</td>
</tr>
<tr>
<td>45.0</td>
<td>24</td>
<td>29</td>
<td>1.042</td>
</tr>
<tr>
<td>55.0</td>
<td>29</td>
<td>32</td>
<td>0.310</td>
</tr>
<tr>
<td>65.0</td>
<td>41</td>
<td>52</td>
<td>2.951</td>
</tr>
<tr>
<td>75.0</td>
<td>49</td>
<td>60</td>
<td>2.469</td>
</tr>
<tr>
<td>85.0</td>
<td>44</td>
<td>51</td>
<td>1.114</td>
</tr>
<tr>
<td>95.0</td>
<td>51</td>
<td>43</td>
<td>1.255</td>
</tr>
<tr>
<td>105.0</td>
<td>79</td>
<td>75</td>
<td>0.203</td>
</tr>
<tr>
<td>115.0</td>
<td>91</td>
<td>94</td>
<td>0.099</td>
</tr>
<tr>
<td>125.0</td>
<td>167</td>
<td>177</td>
<td>0.599</td>
</tr>
<tr>
<td>135.0</td>
<td>273</td>
<td>290</td>
<td>1.059</td>
</tr>
<tr>
<td>145.0</td>
<td>428</td>
<td>411</td>
<td>0.675</td>
</tr>
<tr>
<td>155.0</td>
<td>671</td>
<td>674</td>
<td>0.013</td>
</tr>
<tr>
<td>165.0</td>
<td>733</td>
<td>725</td>
<td>0.087</td>
</tr>
<tr>
<td>175.0</td>
<td>606</td>
<td>584</td>
<td>0.799</td>
</tr>
<tr>
<td>185.0</td>
<td>319</td>
<td>304</td>
<td>0.705</td>
</tr>
<tr>
<td>195.0</td>
<td>176</td>
<td>160</td>
<td>1.455</td>
</tr>
<tr>
<td>205.0</td>
<td>56</td>
<td>68</td>
<td>2.571</td>
</tr>
<tr>
<td>215.0</td>
<td>10</td>
<td>8</td>
<td>0.400</td>
</tr>
<tr>
<td>Total</td>
<td>4113</td>
<td>4120</td>
<td>19.983</td>
</tr>
</tbody>
</table>

ACTUAL-B = Actual Mill B milling rate data collected from the MSC factory laboratory
SIMUL-B = Simulated Mill B milling rate values obtained after running the model for a long period

\[ \chi^2_{critical} = \chi^2_{0.05}, \quad 22 \ df = 33.90 \]

Conclusion: There is no statistical evidence to suggest that the simulated and the actual milling rates data for mill A come from two different populations. Thus, the simulated milling rates generated by the model for Mill B are statistically acceptable within the set limits.
Figure 5.7: Actual and simulated Mill A milling rates frequency distribution

Figure 5.8: Actual and Simulated Mill B milling rates frequency distribution
Investigations were also carried out to determine internal validity of the simulated milling rates (i.e. whether the various simulation runs, generated milling rates that were significantly different). This was done to test the internal validity of the milling rates procedure. Four runs, each run for a duration of one week (7 days) were carried out. The mean of each day's simulated milling rates were determined and treated as individual data for statistical analysis. An analysis of variance (ANOVA) was performed at 5% confidence level using the following hypotheses:-

\[ \text{H}_0: \text{The simulated milling rates are not dependent on the runs.} \]
\[ \text{H}_1: \text{The simulated milling rates are dependent on the runs.} \]

**Table 5.9:** Mean simulated milling rate values for Mill A obtained from different simulation runs

<table>
<thead>
<tr>
<th></th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>107.9</td>
<td>98.3</td>
<td>103.1</td>
<td>102.3</td>
</tr>
<tr>
<td>R2</td>
<td>101.0</td>
<td>100.4</td>
<td>105.5</td>
<td>107.9</td>
</tr>
<tr>
<td>R3</td>
<td>96.9</td>
<td>105.8</td>
<td>101.9</td>
<td>106.9</td>
</tr>
<tr>
<td>R4</td>
<td>86.9</td>
<td>107.5</td>
<td>92.9</td>
<td>110.4</td>
</tr>
<tr>
<td></td>
<td>97.1</td>
<td>100.2</td>
<td>94.6</td>
<td>104.0</td>
</tr>
<tr>
<td></td>
<td>100.7</td>
<td>94.2</td>
<td>103.5</td>
<td>81.9</td>
</tr>
<tr>
<td></td>
<td>101.1</td>
<td>109.0</td>
<td>115.8</td>
<td>113.2</td>
</tr>
</tbody>
</table>

\[ S = \text{Block (Run) totals} \]
\[ SS = \text{Block sum of squares.} \]
\[ \text{Mean} = \text{Block mean.} \]

**Table 5.10:** ANOVA table for Mill A milling rates

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>S</th>
<th>MS</th>
<th>Observed F</th>
<th>Tabulated F 5%</th>
<th>Tabulated F 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>3</td>
<td>96.27</td>
<td>31.76</td>
<td>0.544</td>
<td>3.01</td>
<td>4.72</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>1400.81</td>
<td>58.37</td>
<td>58.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>1496.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Observed F statistic is not significant.

**Conclusion:** There is no significant difference between the simulation runs. Thus, the average daily milling rates for Mill A do not dependent on the runs.
Similar investigations were carried out for the simulated Mill B milling rate values. The results obtained are presented in Table 5.11. Presented in Table 5.12 are the ANOVA results obtained for Mill B simulated milling rates.

Table 5.11: Mean simulated milling rate values for Mill B obtained from different simulation runs

<table>
<thead>
<tr>
<th></th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>162.9</td>
<td>123.1</td>
<td>139.8</td>
<td>136.5</td>
</tr>
<tr>
<td>2</td>
<td>132.9</td>
<td>123.9</td>
<td>137.1</td>
<td>139.8</td>
</tr>
<tr>
<td>3</td>
<td>144.4</td>
<td>124.8</td>
<td>156.3</td>
<td>127.1</td>
</tr>
<tr>
<td>4</td>
<td>141.7</td>
<td>133.2</td>
<td>149.2</td>
<td>123.3</td>
</tr>
<tr>
<td>5</td>
<td>150.4</td>
<td>125.6</td>
<td>138.8</td>
<td>137.9</td>
</tr>
<tr>
<td>6</td>
<td>130.6</td>
<td>143.3</td>
<td>134.0</td>
<td>149.2</td>
</tr>
<tr>
<td>7</td>
<td>136.2</td>
<td>140.6</td>
<td>147.9</td>
<td>133.1</td>
</tr>
</tbody>
</table>

\[S = \text{Block (Run) totals}\]
\[SS = \text{Block sum of squares.}\]
\[\text{Mean} = \text{Block mean.}\]
\[R1, \ldots, R4 = \text{Seven days continuous simulation runs}\]

Table 5.12: ANOVA table for Mill B milling rates

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>(SS)</th>
<th>(MS)</th>
<th>(\text{Observed F})</th>
<th>(\text{Tabulated F})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>3</td>
<td>477.38</td>
<td>159.1</td>
<td>2.455</td>
<td>3.01 4.72</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>1555.80</td>
<td>64.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>2033.10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: There is no significant difference between the simulation runs. Thus, the average daily milling rates for Mill B do not depend on the runs' start point. Similar milling rate values may be obtained from any sequence of random number assigned to the milling rate value.

From the statistical analysis carried out, it was established that the milling rates generated by the simulation model are not dependent on the simulation runs’ starting point over a twenty-four hour period. Therefore, the same distribution of the milling rates for both mills can be reproduced using any number of simulation runs using any sequence of random numbers from \texttt{rng} procedure.
5.2.2 Waiting time of trailers in the Cane Yard

The efficiency of the Cane Yard operations can be estimated by considering the time a unit (trailer) spends in the yard. In working out the waiting time of the various trailer types that haul cane to the yard, it was assumed that for any chosen hour of operation, the units that come for unloading arrive and queue behind the server at the beginning of that hour. Thus if \( n \) units arrived at the beginning of a certain hour and each had a service (unloading) time of \( T_1, T_2, ..., T_n \), then the average waiting time is given by Equation (4.14).

When no unloading occurred during the hour, due to some problems in factory operations, the average waiting time for the given unit type that were not unloaded was taken to be 60 minutes. However, if during that hour not all the units were unloaded, the average waiting time of the unit type being considered during that hour was given by Equation (4.15).

In validating the Delivery/Wating Time Procedure, the simulated and the actual waiting time for a given truck type, through a given weighbridge (if applicable) were compared. This was done by performing a t-test on the simulated data for a sample size of 24 (i.e 24 days simulation run means) at 5\% confidence level. The hypothesis tested in this case was:

- \( H_0: \) There is no difference between the means of simulated and actual waiting times of a chosen trailer type.
- \( H_1: \) The means of simulated and actual waiting times of the chosen trailer types are different.

A two tailed t-test (Steel and Torrie, 1987) was performed for the following trailer types:

1. Waiting times of basket type trailers through weighbridge A, WBA.
2. Waiting time of basket type trailers through weighbridge B, WBB.
3. Waiting time of the self tipping trailers, WST.
4. Waiting times of the ordinary bundle trailers. These are unloaded by the gantry cranes, WGC.
Presented in Table 5.13 are the daily mean waiting times obtained from the simulation model for a continuous run duration equal to 24 days. Table 5.14 gives the mean of the waiting time of the collected data, the standard deviation and the observed (actual) mean waiting times.

In comparing the simulated and the real operational conditions waiting time (i.e. time a unit spends in the Cane Yard), t-test was performed at 5% significance level on all the waiting times data presented in Table 5.13. The historical and simulation model’s waiting times data were averaged to give the mean population and simulated waiting times respectively. The population mean waiting times for all the cane trailers are given in Table 5.14 in the column under μ while those from the model are under X.

Table 5.13: Mean waiting time data obtained from a 24 day simulation run for all trailer types

<table>
<thead>
<tr>
<th>WBA</th>
<th>WBB</th>
<th>WST</th>
<th>WGC</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.8</td>
<td>24.8</td>
<td>14.9</td>
<td>37.8</td>
</tr>
<tr>
<td>22.6</td>
<td>14.8</td>
<td>19.0</td>
<td>37.4</td>
</tr>
<tr>
<td>21.5</td>
<td>17.5</td>
<td>24.9</td>
<td>41.2</td>
</tr>
<tr>
<td>20.9</td>
<td>18.1</td>
<td>29.0</td>
<td>36.1</td>
</tr>
<tr>
<td>13.5</td>
<td>22.7</td>
<td>10.8</td>
<td>34.8</td>
</tr>
<tr>
<td>17.1</td>
<td>17.3</td>
<td>20.9</td>
<td>41.1</td>
</tr>
<tr>
<td>19.1</td>
<td>21.5</td>
<td>20.6</td>
<td>31.1</td>
</tr>
<tr>
<td>21.5</td>
<td>18.2</td>
<td>30.4</td>
<td>32.6</td>
</tr>
<tr>
<td>19.7</td>
<td>19.3</td>
<td>28.5</td>
<td>30.2</td>
</tr>
<tr>
<td>22.8</td>
<td>15.7</td>
<td>24.8</td>
<td>34.8</td>
</tr>
<tr>
<td>17.5</td>
<td>21.4</td>
<td>22.1</td>
<td>42.7</td>
</tr>
<tr>
<td>18.5</td>
<td>12.3</td>
<td>22.5</td>
<td>36.3</td>
</tr>
<tr>
<td>15.2</td>
<td>20.5</td>
<td>23.4</td>
<td>41.5</td>
</tr>
<tr>
<td>27.1</td>
<td>16.0</td>
<td>23.6</td>
<td>32.9</td>
</tr>
<tr>
<td>14.9</td>
<td>14.5</td>
<td>18.1</td>
<td>31.3</td>
</tr>
<tr>
<td>13.1</td>
<td>12.3</td>
<td>26.8</td>
<td>46.5</td>
</tr>
<tr>
<td>18.5</td>
<td>17.7</td>
<td>23.3</td>
<td>36.3</td>
</tr>
<tr>
<td>21.1</td>
<td>16.5</td>
<td>17.6</td>
<td>38.9</td>
</tr>
<tr>
<td>20.2</td>
<td>15.3</td>
<td>28.7</td>
<td>31.8</td>
</tr>
<tr>
<td>12.2</td>
<td>16.1</td>
<td>24.5</td>
<td>37.2</td>
</tr>
<tr>
<td>20.5</td>
<td>18.5</td>
<td>24.9</td>
<td>34.5</td>
</tr>
<tr>
<td>17.2</td>
<td>14.8</td>
<td>26.0</td>
<td>36.7</td>
</tr>
<tr>
<td>13.5</td>
<td>14.6</td>
<td>26.6</td>
<td>36.3</td>
</tr>
<tr>
<td>12.5</td>
<td>18.1</td>
<td>16.2</td>
<td>34.3</td>
</tr>
</tbody>
</table>

WBA = Waiting time of Basket type trailers unloaded by Hydro-Loader A.
WBB = Waiting time of Basket type trailers unloaded by Hydro-Loader B.
WST = Waiting time of the Self-tipping bundle trailers.
WGC = Waiting time of Ordinary bundle trailers unloaded by the Gantry Cranes.
Table 5.14: Results of the waiting times data obtained from a 24 day simulation run

<table>
<thead>
<tr>
<th></th>
<th>( \mu )</th>
<th>( X )</th>
<th>( \sigma_{n-1} )</th>
<th>( t_{\text{calculated}} )</th>
<th>( t_{\text{tabulated}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBA</td>
<td>23</td>
<td>18.2</td>
<td>3.859</td>
<td>-6.094*</td>
<td>2.069</td>
</tr>
<tr>
<td>WBB</td>
<td>23</td>
<td>17.5</td>
<td>3.130</td>
<td>-8.608*</td>
<td>2.069</td>
</tr>
<tr>
<td>WST</td>
<td>24</td>
<td>22.8</td>
<td>4.857</td>
<td>-1.210</td>
<td>2.069</td>
</tr>
<tr>
<td>WGC</td>
<td>38</td>
<td>36.4</td>
<td>4.054</td>
<td>-1.933</td>
<td>2.069</td>
</tr>
</tbody>
</table>

*Significant at 5% level.

- \( \mu \) - Actual mean waiting times for various truck types.
- \( X \) - Simulated mean waiting times for various truck types.
- \( \sigma_{n-1} \) - Variance for the simulated waiting times.

**Conclusion:** From the foregoing statistical analysis, the waiting times of Loose cane trailers (basket) are significant at 5% level for units that serve Mill A and Mill B sides. The waiting times for the Self-tipping trailers and the Ordinary bundled trailers are not significant at 5% confidence level.

The waiting times generated by the model for the Loose (Basket) trailers are observed to be lower than the actual waiting times. This could have arisen as a result of:-

1. The waiting time calculated by the simulation model does not incorporate the time that a unit spends in the yard while travelling from the service point to the weighbridge on its way to the field (see Equation 4.14 and 4.15).
2. The time that a truck spends on the weighbridge while queuing on its way out and while being weighed out on the weighbridge.
3. At times, there are delays such that after one unit has already completed service, the unit behind it does not enter the serving point immediately.

It should be noted that the average waiting time estimation by the model assumes that there is no time lost between the end of serving one unit and the starting of serving of the next unit. This is practically impossible and should be considered as another reason as to why the mean simulated waiting times for all truck types are all lower than the actual waiting time mean value.
5.2.3 Cane Delivery

In order to use the transform method to simulate the number of arriving units for a given trailer type from the field, the mean hourly arrival rates of Loose cane and Bundle cane units were obtained by converting the hourly mean cane tonnages (see Appendix 1) to the average number of units. For a Basket cane trailer, the mean hourly cane delivery was divided by 6.5 tonne/unit (average Loose cane unit weight) while for Bundled cane units (a Double Bundle being considered as two separate units) the mean hourly cane delivery tonnage was divided by 6.0. Mean hourly cane delivery units obtained are presented in Table 5.15.

To use the mean hourly units delivered for each trailer type as input to the model, the contents of Table 5.15 were keyed into a sequential file which was later accessed by the computer program during execution. For a given hour, the program read the HOUR, ABK, BBK and ABBD. The relevant parameters were then supplied as input to the model at the appropriate stages in the program to simulate the various trailer types cane deliveries during the hour in question.

From the results presented in Table 5.15, the mean number of cane units delivered were observed to be dependent on the hour of operation. This confirmed the observations of Kamau and Kiteshuo (1991). It was interestingly observed that the maximum cane deliveries for the first two shifts of the day occurred during the last hour of the shifts. This observation was attributed to the shifts change-over which takes place (MSC fleet) at the yard during the last hour of the shifts.

In order to take care of this "shift change-over effects", the shift change-over place should be dependent on the location of the cane transport trailer concerned. This can be achieved by not fixing the location in which change over occurs. The location of the cane transport trailers should thus be monitored. The monitoring of the cane transport trailers location can easily be done using the available Radio Call system. Once the location of such a tractor is known, it can be traced towards the end of shift and the changing-over done without wasting
a lot time. Such an action will ensure that cane arrival in the yard is maintained at a level that can be comfortably handled using the current unloading equipment.

Table 5.15: Mean hourly number of Loose and Bundle cane units

<table>
<thead>
<tr>
<th>HOUR</th>
<th>ABK</th>
<th>BBK</th>
<th>ABBD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>6.66</td>
<td>4.31</td>
<td>18.74</td>
</tr>
<tr>
<td>1.00</td>
<td>6.84</td>
<td>4.18</td>
<td>17.34</td>
</tr>
<tr>
<td>2.00</td>
<td>6.72</td>
<td>8.22</td>
<td>17.57</td>
</tr>
<tr>
<td>3.00</td>
<td>6.05</td>
<td>6.82</td>
<td>16.65</td>
</tr>
<tr>
<td>4.00</td>
<td>5.72</td>
<td>6.95</td>
<td>15.82</td>
</tr>
<tr>
<td>5.00</td>
<td>6.94</td>
<td>13.08</td>
<td>16.37</td>
</tr>
<tr>
<td>6.00</td>
<td>5.13</td>
<td>7.00</td>
<td>16.30</td>
</tr>
</tbody>
</table>

ABK - Basket type trailers through Weighbridge A.
BBK - Basket type trailers through Weighbridge B.
ABBD - Double and single bundle units (Self-tipping units inclusive)

In establishing the validity of the DELIVERIES sub-program, the mean cane delivered by end of 14th and 21st hours for 20 days simulation runs were compared with the expected (mean) cane deliveries for these hours under the actual operating condition. This analysis was carried out by performing a two tailed t-test for each selected hour at 5% significance level for ABK, BBK, and ABBD. Data obtained from the model output and used in the t-test for the selected hours together with the results of the analysis are present in Tables 5.16 and 5.17.
Table 5.16: Simulated units delivery at 14.00 Hours

<table>
<thead>
<tr>
<th></th>
<th>NBA</th>
<th>NBB</th>
<th>NBD</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>23</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>22</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>25</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>22</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>33</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>28</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>30</td>
<td>58</td>
<td></td>
</tr>
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<td>21</td>
<td>23</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>35</td>
<td>44</td>
<td></td>
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<td>18</td>
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<td>11</td>
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<td>14</td>
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<td>23</td>
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<td>16</td>
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<td>51</td>
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<td>15</td>
<td>29</td>
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<td></td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>58</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Actual mean</th>
<th>Simulated mean</th>
<th>Standard deviation</th>
<th>t-calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBA</td>
<td>19.29</td>
<td>18.20</td>
<td>3.32</td>
<td>-1.47</td>
</tr>
<tr>
<td>NBB</td>
<td>25.55</td>
<td>26.70</td>
<td>5.01</td>
<td>1.03</td>
</tr>
<tr>
<td>NBD</td>
<td>50.76</td>
<td>49.20</td>
<td>7.81</td>
<td>-0.89</td>
</tr>
</tbody>
</table>

NBA - Number of Basket arrivals through Weighbridge A.
NBB - Number of Basket arrivals through Weighbridge B.
NBD - Number of Bundle arrival through both Weighbridges.

Conclusion: There is no statistical evidence to suggest that the simulated cane delivery rates during the 14th hour are different from the actual cane delivery rates.

The cane delivery sub-program (procedure) therefore generates cane delivery rates that are statistically acceptable as coming from the same population as the actual cane delivery rate data for various truck types through the two Weighbridges. Since for the selected hours there is no statistical difference between the simulated and the actual cane delivered by the various truck types, the same argument should hold for the other hours as the only changing factor is the mean hourly delivery rate (Table 5.15).
Table 5.17: Simulated units delivery at 21.00 Hours

<table>
<thead>
<tr>
<th>NBA</th>
<th>NBB</th>
<th>NBD</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>19</td>
<td>36</td>
</tr>
<tr>
<td>16</td>
<td>15</td>
<td>32</td>
</tr>
<tr>
<td>12</td>
<td>18</td>
<td>38</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>31</td>
</tr>
<tr>
<td>18</td>
<td>16</td>
<td>38</td>
</tr>
<tr>
<td>11</td>
<td>19</td>
<td>43</td>
</tr>
<tr>
<td>15</td>
<td>12</td>
<td>31</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>16</td>
<td>9</td>
<td>22</td>
</tr>
<tr>
<td>9</td>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td>11</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>42</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
<td>34</td>
</tr>
<tr>
<td>14</td>
<td>13</td>
<td>35</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>29</td>
</tr>
<tr>
<td>16</td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
<td>25</td>
</tr>
</tbody>
</table>

Actual mean | 11.33 | 13.89 | 32.87 |
Sample mean | 12.05 | 14.35 | 32.05 |
Standard deviation | 2.98 | 3.82 | 6.35 |
Calculated t-value | 1.08 | 0.54 | -0.58 |

Conclusion: There is no statistical evidence to suggest that the simulated cane delivery rates during the 21st hour are different from the actual cane delivery rates at 5% level.

5.3 Simulation Experiments

5.3.1 Altering the number of unloading Gantry cranes

The experiments were designed to evaluate the effect of the number of the working Gantry cranes on the average hourly waiting time for the Bundle cane trailers unloaded by the Gantry cranes. In the experiments, for a given simulation run, the availability of a fixed number of Gantry cranes for unloading operation is taken to be 100%. In order to compare the average waiting times, the daily average waiting time data was collected from the simulation runs for a given fixed number of operating Gantry cranes. For each experiment, 10 days were
simulated. The data obtained from the simulation runs, are presented in Table 5.18 below.

**Table 5.18: Waiting times data for various numbers of fixed unloading Gantry cranes**

<table>
<thead>
<tr>
<th>DAY</th>
<th>N=2</th>
<th>N=3</th>
<th>N=4</th>
<th>N=5</th>
<th>CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>52.1</td>
<td>27.6</td>
<td>29.1</td>
<td>29.9</td>
<td>31.2</td>
</tr>
<tr>
<td>2</td>
<td>53.5</td>
<td>29.3</td>
<td>28.0</td>
<td>26.8</td>
<td>33.1</td>
</tr>
<tr>
<td>3</td>
<td>49.4</td>
<td>28.1</td>
<td>26.4</td>
<td>27.3</td>
<td>39.8</td>
</tr>
<tr>
<td>4</td>
<td>53.4</td>
<td>31.8</td>
<td>29.8</td>
<td>27.7</td>
<td>38.6</td>
</tr>
<tr>
<td>5</td>
<td>54.5</td>
<td>28.5</td>
<td>26.8</td>
<td>25.2</td>
<td>31.2</td>
</tr>
<tr>
<td>6</td>
<td>52.0</td>
<td>27.2</td>
<td>29.9</td>
<td>27.4</td>
<td>36.8</td>
</tr>
<tr>
<td>7</td>
<td>53.1</td>
<td>35.0</td>
<td>27.1</td>
<td>27.9</td>
<td>36.0</td>
</tr>
<tr>
<td>8</td>
<td>50.0</td>
<td>30.1</td>
<td>28.3</td>
<td>28.5</td>
<td>38.7</td>
</tr>
<tr>
<td>9</td>
<td>54.0</td>
<td>29.3</td>
<td>27.9</td>
<td>28.1</td>
<td>34.5</td>
</tr>
<tr>
<td>10</td>
<td>51.2</td>
<td>29.7</td>
<td>29.1</td>
<td>28.7</td>
<td>31.9</td>
</tr>
</tbody>
</table>

N = Number of Gantry cranes engaged to do bundled cane unloading for a given simulation run. This is fixed for a duration equivalent to 10 days in the above experiments.

CONTROL = Normal operating Cane Yard operations.

A casual look at the columns in Table 5.18 shows that the average waiting times for N = 2 are obviously higher than the rest. In order to compare the effect of the numbers of working Gantry cranes for N = 3, N = 4, N = 5 and the control (i.e. normal operating condition when the number of working Gantry cranes vary during simulation programs execution), Analysis of variance technique (ANOVA) was employed at 5% significance level to test the following hypothesis:-

Hₐ: There is no difference between waiting times for N=3, N=4, N=5 and the control.

H₁: There is a difference between waiting times for N=3, N=4, N=5 and the control.

The results obtained after analyzing the data are presented in Table 5.19.
Conclusion: Effect of the number of working Gantry cranes on the average waiting time of ordinary bundle trailers is significant. Thus, the number of operating Gantry cranes have an effect on the average waiting time of the Ordinary Bundle trailers.

From the preliminary simulation runs for these experiments it was observed that operating 5 Gantry cranes to unload the cane resulted in some channels (at least one per hour) being idle during an hour of operation. Also from Table 5.18 the effect of 4 or 5 Gantry cranes operating throughout was analyzed. ANOVA was used to test whether the waiting time values obtained from the model were statistically significant. The results of the analysis are presented in Table 5.20 below.

Table 5.20: ANOVA table for $N = 4$ and $N=5$ on the average waiting times

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>S</th>
<th>MS</th>
<th>F-calculated</th>
<th>F-tabulated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F 5%</td>
<td>F 1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gantry</td>
<td>1</td>
<td>1.2005</td>
<td>1.2005</td>
<td>0.734</td>
<td>4.41</td>
</tr>
<tr>
<td>Error</td>
<td>18</td>
<td>27.569</td>
<td>1.532</td>
<td></td>
<td>8.29</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>28.7695</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: The effect of 4 or 5 Gantry cranes operating on the average waiting time of the Ordinary Bundle trailers is not significant.

Also investigated was whether there exists a difference on the average waiting time when we have 3 and 4 cranes operating. Results of the analysis based on Table 5.18 are presented in Table 5.21.
Table 5.21: ANOVA Table for N=3 and N=4 on the average waiting time

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>S</th>
<th>MS</th>
<th>F-calculated</th>
<th>5%</th>
<th>1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantry</td>
<td>1</td>
<td>10.082</td>
<td>10.082</td>
<td>2.964</td>
<td>4.41</td>
<td>8.29</td>
</tr>
<tr>
<td>Error</td>
<td>18</td>
<td>61.228</td>
<td>3.402</td>
<td>6.01</td>
<td>7.05</td>
<td>11.90</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>71.310</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: Not significant. Thus as far as the average waiting times are concerned, when 3 or 4 Gantry cranes are used in unloading the ordinary bundle cane trailers, there is no significant difference in the average waiting times.

Since statistical analysis indicate that there is no significant difference when three (3) or four (4) Gantry cranes are deployed to do the unloading work, three (3) Gantry cranes should be available at any operating time to unload the Ordinary Bundle trailers. The fourth Gantry crane should also be in functional status, but should be employed to feed the mills. However when one of the three cranes become unavailable through breakdowns, the fourth Gantry crane should replace the one that is broken down. By looking at the data gathered from the simulation runs, i.e, Tables 5.13 and 5.18, it is obvious that currently the number of Gantry cranes available for unloading Bundle cane trailers on average, are not adequate. This is due the fact that for normal operating conditions, high average waiting times (usually more than the 30 minutes budget) is obtained for the real and simulated average waiting times for the Gantry cranes unloaded Bundle cane trailers.

5.3.2 Effects of shifting bundles to Loose cane units

Simulation runs were carried out to determine the effect of transferring 4 and 6 Bundle cane units to Loose cane units. Loose cane through each weighbridge was increased by equal amounts, i.e, 2 and 3 respectively for each experimental operating conditions. Three simulation runs, each for a period of 10 days were conducted and data collected. The daily mean waiting times data for Loose cane units through weighbridges A and B, and Gantry cranes unloaded cane trailers collected. Data collected and their results, and analysis performed are presented in the Tables 5.22 to 5.27.
Table 5.24: Mill B side Loose cane trailers average waiting times for various conditions

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>N+2</th>
<th>N+3</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.8</td>
<td>19.3</td>
<td>23.1</td>
<td></td>
</tr>
<tr>
<td>14.0</td>
<td>20.8</td>
<td>19.7</td>
<td></td>
</tr>
<tr>
<td>14.8</td>
<td>23.4</td>
<td>15.6</td>
<td></td>
</tr>
<tr>
<td>14.1</td>
<td>19.2</td>
<td>27.8</td>
<td></td>
</tr>
<tr>
<td>16.8</td>
<td>16.3</td>
<td>26.8</td>
<td></td>
</tr>
<tr>
<td>17.3</td>
<td>20.2</td>
<td>17.0</td>
<td></td>
</tr>
<tr>
<td>27.5</td>
<td>22.7</td>
<td>19.3</td>
<td></td>
</tr>
<tr>
<td>16.3</td>
<td>23.4</td>
<td>20.8</td>
<td></td>
</tr>
<tr>
<td>18.9</td>
<td>24.1</td>
<td>30.5</td>
<td></td>
</tr>
<tr>
<td>13.5</td>
<td>22.0</td>
<td>21.1</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>169.00</td>
<td>211.40</td>
<td>221.70</td>
</tr>
<tr>
<td>SS</td>
<td>3006.42</td>
<td>4522.72</td>
<td>5125.73</td>
</tr>
<tr>
<td>Mean</td>
<td>16.90</td>
<td>21.14</td>
<td>22.17</td>
</tr>
<tr>
<td>Variance</td>
<td>4.09</td>
<td>2.44</td>
<td>4.84</td>
</tr>
</tbody>
</table>

Table 5.25: ANOVA table for waiting time of Loose cane units on Mill B side

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>S</th>
<th>MS</th>
<th>F-calculated</th>
<th>F-tabulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columns</td>
<td>2</td>
<td>156.038</td>
<td>78.019</td>
<td>5.08*</td>
<td>3.35</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>414.685</td>
<td>15.359</td>
<td></td>
<td>5.49</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>570.723</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Significant at 5% level.

Conclusion: The waiting times of Loose cane (Basket type) trailer feeding Mill B are significant at 5% level. Therefore shifting of Bundle trailers to Loose cane trailers affects the waiting times of loose cane trailers.

Finally, waiting times data was gathered for the bundled cane trailers unloaded by the Gantry cranes to establish whether transferring bundle cane units results in lowering the waiting time of the bundled cane trailers. Results and analysis of the data collected are presented in Tables 5.26 and 5.27.
Table 5.26: Waiting times for Bundle cane trailers unloaded by the Gantry cranes

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>N-4</th>
<th>N-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>39.3</td>
<td>32.4</td>
<td>30.5</td>
<td></td>
</tr>
<tr>
<td>43.8</td>
<td>31.5</td>
<td>26.7</td>
<td></td>
</tr>
<tr>
<td>38.1</td>
<td>29.5</td>
<td>23.0</td>
<td></td>
</tr>
<tr>
<td>35.9</td>
<td>29.2</td>
<td>30.2</td>
<td></td>
</tr>
<tr>
<td>42.6</td>
<td>27.6</td>
<td>30.8</td>
<td></td>
</tr>
<tr>
<td>37.5</td>
<td>26.3</td>
<td>27.0</td>
<td></td>
</tr>
<tr>
<td>38.8</td>
<td>31.3</td>
<td>27.5</td>
<td></td>
</tr>
<tr>
<td>38.5</td>
<td>29.8</td>
<td>31.0</td>
<td></td>
</tr>
<tr>
<td>31.6</td>
<td>33.9</td>
<td>27.2</td>
<td></td>
</tr>
<tr>
<td>34.0</td>
<td>35.3</td>
<td>32.1</td>
<td></td>
</tr>
</tbody>
</table>

\[s\]

\[\text{Mean}\]

\[
\text{Variance}
\]

Table 5.27: ANOVA table for Gantry cranes unloading times after transferring 4 and 6 Bundle units to Loose cane units

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>S</th>
<th>MS</th>
<th>F-calculated</th>
<th>F-tabulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column</td>
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<td>306.321</td>
<td>153.161</td>
<td>9.376*</td>
<td>3.35 5.49</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>441.053</td>
<td>16.335</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>747.374</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5% level.

Conclusion: The waiting times of Gantry crane unloaded bundle trailers are significant. The treatment (shifting Bundles to Loose cane) affects the waiting time of the bundled cane trailers. The analysis show that the waiting times of the Bundle cane units may be reduced by shifting some Bundled cane trailer units to Loose cane units.

5.3.3 Possibility of a Two-Shift Hauling System

A simulation experiment was carried out to determine the possibility of using only two shifts of eight hours each for hauling cane from the fields to the mill. In order that the mills requirements are satisfied (i.e cane be available for milling in the Cane Yard until 6.00 Hours of the following day), then all the cane that is hauled to the Cane Yard during the third shift of the day had to be hauled in during the first two shifts. In doing this, the hourly mean cane delivery rates for various cane trailer types were summed up for the last shift and then
divided by sixteen (16) hours to give an additional cane delivery rate per hour for each trailer type. These were then added on to the average hourly delivery rates for the first 16 hours of the day.

Using the new mean delivery rates, a simulation run spanning 20 days was carried out and the mean waiting times data for various trailers types collected for each day. The results obtained from the simulation run are presented in Table 5.28 below.

Table 5.28: Results of the simulation run for a Two-Shift experiment

<table>
<thead>
<tr>
<th></th>
<th>WBA</th>
<th>WBB</th>
<th>WST</th>
<th>WGC</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.9</td>
<td>28.1</td>
<td>27.7</td>
<td>46.3</td>
<td></td>
</tr>
<tr>
<td>16.9</td>
<td>18.6</td>
<td>22.9</td>
<td>41.5</td>
<td></td>
</tr>
<tr>
<td>30.8</td>
<td>22.7</td>
<td>35.4</td>
<td>45.8</td>
<td></td>
</tr>
<tr>
<td>26.8</td>
<td>25.6</td>
<td>27.4</td>
<td>52.1</td>
<td></td>
</tr>
<tr>
<td>18.1</td>
<td>23.9</td>
<td>30.9</td>
<td>45.9</td>
<td></td>
</tr>
<tr>
<td>29.1</td>
<td>26.4</td>
<td>25.9</td>
<td>43.4</td>
<td></td>
</tr>
<tr>
<td>35.4</td>
<td>28.3</td>
<td>34.4</td>
<td>42.4</td>
<td></td>
</tr>
<tr>
<td>24.5</td>
<td>20.4</td>
<td>39.4</td>
<td>45.1</td>
<td></td>
</tr>
<tr>
<td>22.9</td>
<td>23.5</td>
<td>30.2</td>
<td>51.7</td>
<td></td>
</tr>
<tr>
<td>18.0</td>
<td>20.1</td>
<td>26.3</td>
<td>46.8</td>
<td></td>
</tr>
<tr>
<td>33.7</td>
<td>30.7</td>
<td>32.0</td>
<td>44.8</td>
<td></td>
</tr>
<tr>
<td>31.1</td>
<td>28.0</td>
<td>35.8</td>
<td>42.1</td>
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</tr>
<tr>
<td>49.9</td>
<td>31.1</td>
<td>43.1</td>
<td>43.9</td>
<td></td>
</tr>
<tr>
<td>16.1</td>
<td>24.6</td>
<td>30.9</td>
<td>48.9</td>
<td></td>
</tr>
<tr>
<td>36.8</td>
<td>30.3</td>
<td>32.1</td>
<td>44.1</td>
<td></td>
</tr>
<tr>
<td>27.7</td>
<td>29.8</td>
<td>43.6</td>
<td>46.1</td>
<td></td>
</tr>
<tr>
<td>39.9</td>
<td>26.4</td>
<td>34.1</td>
<td>44.7</td>
<td></td>
</tr>
<tr>
<td>41.6</td>
<td>25.1</td>
<td>38.6</td>
<td>48.2</td>
<td></td>
</tr>
<tr>
<td>46.4</td>
<td>33.8</td>
<td>39.5</td>
<td>41.7</td>
<td></td>
</tr>
<tr>
<td>27.3</td>
<td>27.6</td>
<td>19.1</td>
<td>45.1</td>
<td></td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>29.8</strong></td>
<td><strong>26.3</strong></td>
<td><strong>32.5</strong></td>
<td><strong>45.5</strong></td>
</tr>
</tbody>
</table>

Apart from carrying out the simulation experiments to establish the effects of transferring all the cane hauled to the Cane Yard during the third shift (22.00 hours to 6.00 hours) in equal amounts to the first two shifts and parking all cane transportation units by 22.00 hours on the daily average waiting time for all unit types, experiments were also conducted to establish the effect(s) of the fixed number of Gantry cranes on daily average waiting time for a Two Shift system. This latter experiment was prompted by the fact that the daily average waiting time for all units increased tremendously when extra units were added to ensure that the total daily
average cane requirements were met by operating two shifts of 8 hours each.

Experimental runs were performed with fixed numbers of Gantry cranes equal to 3 and 4. The daily mean waiting times data for a duration of 10 days for each experimental set up was collected. In order to compare the waiting time results obtained from the experimental runs, a One Way Analysis of variance at 5% confidence level was performed. Results of the data obtained and analysis are presented in Table 5.29 through to 5.34.

Table 5.29: Waiting time for Basket (bin) trailers passing through weighbridge A during a Two-Shift experiment

<table>
<thead>
<tr>
<th>DAY</th>
<th>2SN</th>
<th>2SGC3</th>
<th>2SGC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32.90</td>
<td>21.40</td>
<td>21.90</td>
</tr>
<tr>
<td>2</td>
<td>16.90</td>
<td>32.30</td>
<td>23.00</td>
</tr>
<tr>
<td>3</td>
<td>30.80</td>
<td>15.90</td>
<td>40.00</td>
</tr>
<tr>
<td>4</td>
<td>26.80</td>
<td>34.40</td>
<td>47.60</td>
</tr>
<tr>
<td>5</td>
<td>18.10</td>
<td>42.90</td>
<td>43.60</td>
</tr>
<tr>
<td>6</td>
<td>29.10</td>
<td>40.10</td>
<td>24.90</td>
</tr>
<tr>
<td>7</td>
<td>35.40</td>
<td>31.10</td>
<td>18.40</td>
</tr>
<tr>
<td>8</td>
<td>24.50</td>
<td>23.60</td>
<td>25.30</td>
</tr>
<tr>
<td>9</td>
<td>22.90</td>
<td>20.90</td>
<td>17.40</td>
</tr>
<tr>
<td>10</td>
<td>18.00</td>
<td>20.10</td>
<td>16.90</td>
</tr>
</tbody>
</table>

Terms used in Table 5.29 are:
- **2SN** = Two shift with normal number of operating Gantry cranes.
- **2SGC3** = Two shifts with 3 Gantry cranes operating throughout.
- **2SGC4** = Two shifts with 4 Gantry cranes operating throughout.

Table 5.30: ANOVA table for data in Table 5.29

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F-calculated</th>
<th>F-tabulated 5%</th>
<th>F-tabulated 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>2</td>
<td>61.47</td>
<td>30.735</td>
<td>0.357</td>
<td>4.21</td>
<td>7.68</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>2327.44</td>
<td>86.053</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>2384.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: Not Significant at 5% and 1% levels.
Table 5.31: Waiting times for Basket trailers passing through weighbridge B during a Two-Shift experiment

<table>
<thead>
<tr>
<th>DAY</th>
<th>2SN</th>
<th>2SGC3</th>
<th>2SGC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.1</td>
<td>19.4</td>
<td>30.2</td>
</tr>
<tr>
<td>2</td>
<td>18.6</td>
<td>21.6</td>
<td>23.3</td>
</tr>
<tr>
<td>3</td>
<td>22.7</td>
<td>42.4</td>
<td>22.0</td>
</tr>
<tr>
<td>4</td>
<td>25.6</td>
<td>27.1</td>
<td>16.0</td>
</tr>
<tr>
<td>5</td>
<td>23.9</td>
<td>28.8</td>
<td>21.4</td>
</tr>
<tr>
<td>6</td>
<td>26.4</td>
<td>25.1</td>
<td>30.1</td>
</tr>
<tr>
<td>7</td>
<td>28.3</td>
<td>23.7</td>
<td>26.6</td>
</tr>
<tr>
<td>8</td>
<td>20.4</td>
<td>35.0</td>
<td>25.3</td>
</tr>
<tr>
<td>9</td>
<td>23.5</td>
<td>24.1</td>
<td>25.0</td>
</tr>
<tr>
<td>10</td>
<td>20.1</td>
<td>26.6</td>
<td>28.1</td>
</tr>
</tbody>
</table>

\[\text{S} \quad 237.6 \quad 272.8 \quad 248.9\]
\[\text{SS} \quad 5747.7 \quad 7857.4 \quad 6350.77\]
\[\text{Mean} \quad 23.76 \quad 27.28 \quad 24.89\]

Notations used are as for Table 5.29

Table 5.32: ANOVA Table for data in Table 5.31

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F-calculated</th>
<th>F-tabulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>2</td>
<td>64.598</td>
<td>32.299</td>
<td>1.283</td>
<td>4.21 7.68</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>673.389</td>
<td>24.940</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>737.987</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusion: Not significant at 5% and 1% confidence levels.

Table 5.33: Waiting times for Bundle cane trailers unloaded by the Gantry cranes during a Two-Shift experiment

<table>
<thead>
<tr>
<th>DAY</th>
<th>2SN</th>
<th>2SGC3</th>
<th>2SGC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>46.3</td>
<td>41.4</td>
<td>29.9</td>
</tr>
<tr>
<td>2</td>
<td>41.5</td>
<td>35.7</td>
<td>29.5</td>
</tr>
<tr>
<td>3</td>
<td>45.8</td>
<td>39.4</td>
<td>30.9</td>
</tr>
<tr>
<td>4</td>
<td>52.1</td>
<td>34.6</td>
<td>29.3</td>
</tr>
<tr>
<td>5</td>
<td>45.9</td>
<td>36.6</td>
<td>30.7</td>
</tr>
<tr>
<td>6</td>
<td>43.4</td>
<td>41.1</td>
<td>27.8</td>
</tr>
<tr>
<td>7</td>
<td>42.4</td>
<td>41.4</td>
<td>31.0</td>
</tr>
<tr>
<td>8</td>
<td>45.1</td>
<td>34.0</td>
<td>30.5</td>
</tr>
<tr>
<td>9</td>
<td>46.8</td>
<td>38.4</td>
<td>31.3</td>
</tr>
<tr>
<td>10</td>
<td>51.7</td>
<td>36.6</td>
<td>29.7</td>
</tr>
</tbody>
</table>

\[\text{Sum} \quad 461.00 \quad 379.20 \quad 300.60\]
\[\text{Sum of Squares} \quad 21363.26 \quad 14448.12 \quad 9045.92\]
\[\text{Mean} \quad 46.10 \quad 37.92 \quad 30.06\]

Notations used are as for Table 5.29
Table 5.34: ANOVA table for Gantry cranes unloaded Bundle trailers

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F-calculated</th>
<th>F-tabulated 5%</th>
<th>F-tabulated 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>2</td>
<td>1286.579</td>
<td>643.290</td>
<td>91.467**</td>
<td>4.21</td>
<td>7.68</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>189.900</td>
<td>7.033</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>1476.479</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Highly significant at both 5% and 1% level

**Conclusion:** The effects of the number of operating Gantry cranes on the waiting times of the Gantry cranes unloaded trailers is highly significant.
6.1 Conclusions

1. The arrival rate of Loose and Bundle cane loaded trailers from the cane fields is dependent on the hour of the day.

2. The flow rate of sugarcane within the Cane Yard is dependent on the trailer type, the milling rate, and unloading space availability.

   (i) The current total Cane Yard stockpiling capacity of 6000 tonnes is adequate to handle all the cane hauled into the Cane Yard by the bundle type trailers.

   (ii) All the unloading equipment, namely the Hydro-Loaders, the Gantry cranes and the Self-tipping trailers have different unloading rates. The Hydro-Loaders have an average unit unloading time of 2.15 minutes. The Gantry cranes have an average unloading time of 4.44 minutes per unit and the Self-tipping trailers have an average unloading time of 7.00 minutes per unit.

   (iii) With the current number of operational Gantry cranes, fitting of a crane with a grab results in reduced unloading rate. This seriously affects the performance of the Ordinary Bundle trailers resulting in long and growing queues.

   (iv) With the current milling rates, cane staleness due to cane staying in the Cane Yard for longer periods is not likely. On average, the cane remaining after a day’s crushing can be crushed within the first shift.

3. The Cane Yard simulation model developed is capable of generating statistically acceptable values for the milling rates, the arrival rates and the service times of all the Cane Yard unloading equipment. However, the mean waiting times for all unit types are under-estimated by the model.
4. From the simulation experiments conducted it can be concluded that:

(i) Effects of shifting Bundles to Loose cane units on the average waiting times is sensitive on both trailer types.

(ii) All cane transport trailers can be parked by the end of 22.00 hour and the milling requirement is still met for the whole day if an equivalent amount of cane delivered during the third shift (i.e between 23.00 hour and 6.00 hour) is hauled in during the first 16 hours of operation (i.e. first two shifts).

(iii) The number of working Gantry cranes (employed purely on unloading) at any chosen hour has a significant effect on the waiting times of the Gantry crane unloaded Bundle cane trailers.

6.2 Recommendations

1. With the current operating conditions, the average waiting times of the Gantry crane unloaded Bundle cane trailers can be lowered appreciably by decreasing the mean arrival rate of these trailers by a rate between 4 to 6 units per hour. This would result in the reduction of the bundle cane trailers average waiting time of 8 minutes and an increase of about 6 minutes and 4 minutes to the waiting time of Loose cane units serving Mills A and B respectively. It is considered that such a reduction in the average waiting time of the Bundle units and the increase in the average waiting times of the Loose cane units will give a more efficient operating Cane Yard system than is the case currently.

2. The idea of parking all the cane hauling units by the end of the sixteenth hour, i.e., using only two shifts of 8 hours each, can only be achieved if the unloading capacities of the Gantry cranes is increased with availability (100% availability) of 3 Gantry cranes during any operational hour. In order to reduce the Loose cane units average waiting times to acceptable levels, not more than 20 minutes (i.e. 120 to 150 tonnes of cane per hour), units should be allowed to queue for service behind Hydro-Loader
A, HYDA, while HYDB should not have more than 27 units in an hour. In case the hourly arrival rate is expected to be higher than these set limits the third Hydro-Loader, HYDC, which at the moment does very little in terms of unloading the Basket trailers should be employed. This Hydro-Loader is capable of unloading about 27 units (the average unloading rate of the Hydro-Loaders) provided that the Front-End Wheel loader is available to clear the unloaded cane away from the unloading site.

3. The waiting times of the Bundle cane trailers can be reduced by transferring some Bundle units to Loose cane units. Such an action would help reduce the idle time of the Hydro-Loaders. Currently the Hydro-Loaders rarely feed the Mill Tables for a duration equal to one hour and the third Hydro-Loader (HYDC) is idle most of the time. This results in Gantry cranes which are fitted with bridles occasionally releasing bundles of cane on the Mill Tables. Such actions increase the service times of the Gantry cranes, eventually affecting the overall waiting time of the Gantry Crane unloaded Bundle cane trailers. Alternatively, a fourth operational Gantry crane should be commissioned to replace inoperable Gantry Crane Number 1, GC1. If this is done then the arrival rate of bundle cane trailers can be left as is at present. This would ensure that the available Gantry cranes at any one given time would be at least three with the fourth being on standby. This would be in agreement with Suttie's recommendation for commissioning of the fifth Gantry crane.

4. The traffic flow within the Cane Yard need to be strictly controlled. Currently the contractors' drivers seem to be causing a lot of trouble, particularly between 12.30 p.m and 2.00 p.m when the arrival rate of all unit types is at maximum. During this period the contractors' drivers in their haste to get their units unloaded do not obey the queue discipline and end up crowding the Cane Yard to the extent of blocking the way out for the units that have already been unloaded. It should be compulsory for all the cane units to follow the marked out routes for incoming and outgoing trailers (Figure 4.2). All Ordinary Bundle trailers should only be unloaded by the Gantry
cranes on FCFS basis.

5. The application of the model developed in this study is limited to the MSC Cane Yard operations only. However, the model forms a basis for analyzing other sugar factories' Cane Yard operations if the pertinent data can be availed and the model modified to describe the lay-out and operations of such companies' Cane Yards. Alternatively, the experience gained in modelling the MSC Cane Yard operations can be applied to developed Cane Yard models for these other sugar factories.

6.3 Future Work

1. There is need to collect data on the time the various unit types spend within the Cane Yard after the unloading operation has been completed and the unit has left the serving point. Data collection for this purpose should include the way out queuing time, the weighbridge weighing out time and the time spent by the units in the Cane Yard while unloading the spilt over cane. This was considered negligible at the start of the study after observing the Cane Yard operations but the waiting times data generated by the model seem to suggest otherwise. The lower simulation model waiting times generated cannot presently be explained convincingly.

2. The simulation model developed assumes that the two major environmental factors namely, rainfall and electrical power availability are favourable throughout. However, this is not the case as electrical power failures occur and heavy rains are known to completely stop the cane loaded units from arriving at the Cane Yard. Therefore, the current model could become more realistic if the stochastic nature of rainfall and electrical power failures can be established and incorporated into the model.

3. A close study on the availability of the Front-End- Wheel loader need to be carried out. In the development of the Cane Yard model it was assumed that this unit was
always available which is not the actual case. The data to be gathered should be aimed at establishing the hourly availability for this unit. This should also be incorporated into the Cane Yard model.

4. There is need for incorporating a feedback loop into the model such that when the arrival of Basket trailers is to exceed 27 units for HYDB and 20 units for HYDA then the extra units are deviated to HYDC. The loop should be extended to cover the Gantry crane unloaded Bundle trailers so as to reduce the average waiting times of these trailers. The inclusion of the loop will make it possible for the model to help answer some of the managerial questions which are not addressed fully by the model in its current form.

5. It was observed that at times the two arms of the weighing bridges are not both operational. When only one side of the bridge operates, queues develop on both sides of the weighbridge with units waiting to be weighed both into and out of the Cane Yard. Such a development, i.e, weighbridge arm breakdowns, have a resultant effect of increased waiting time for all units using such a weighbridge. As such, data should be collected with a view to establishing the hourly weighbridge breakdowns so that their effect on the overall performance of the Cane Yard may be evaluated.

6. Finally, a new study should be undertaken to model the MSC transport system. Once such a model is developed and validated, it should be combined with the Cane Yard model so that a clear picture of the entire MSC cane flow system is established. The transportation model together with the Cane Yard model can provide a useful management tool to the MSC management. This would also help in answering several managerial questions which are not adequately answered by the Cane Yard model satisfactorily.
APPENDICES
This Appendix is a sample sheet of the MSC’s Hourly Cane Delivery Sheet. The terms used in this sheet are:-

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. MSC</td>
<td>Mumias Sugar Company Fleet</td>
<td></td>
</tr>
<tr>
<td>2. DBT</td>
<td>Double Bundle Trailer</td>
<td></td>
</tr>
<tr>
<td>3. SBT</td>
<td>Single Bundle Trailer</td>
<td></td>
</tr>
<tr>
<td>4. NET</td>
<td>Nucleus Estate Trailer (also known as the basket (loose cane) trailer)</td>
<td></td>
</tr>
<tr>
<td>6. TST</td>
<td>Twin Single Trailers (Have been phased out by the company)</td>
<td></td>
</tr>
<tr>
<td>6. MSC TOTAL</td>
<td>Cumulative cane amount delivered by the MSC fleet.</td>
<td></td>
</tr>
<tr>
<td>7. BV ODEDRA</td>
<td>A Contractor with TST trailers.</td>
<td></td>
</tr>
<tr>
<td>8. IMA HAULIER</td>
<td>A contractor with single basket type trailers.</td>
<td></td>
</tr>
<tr>
<td>9. SURGIT SINGH</td>
<td>A contractor with double basket type trailers.</td>
<td></td>
</tr>
<tr>
<td>10. MUSOLA</td>
<td>A contractor with TST trailers.</td>
<td></td>
</tr>
<tr>
<td>11. SONY AGRI</td>
<td>A contractor with single basket type trailers.</td>
<td></td>
</tr>
<tr>
<td>12. MEL</td>
<td>A contractor with single basket type trailers.</td>
<td></td>
</tr>
<tr>
<td>13. EKB</td>
<td>A contractor with single basket type trailers.</td>
<td></td>
</tr>
<tr>
<td>14. BOTH MILL TOTAL</td>
<td>Cumulative amount of cane that has been delivered at the cane yard by all units operating on a given day. Gives a picture of how well the delivery of cane is.</td>
<td></td>
</tr>
<tr>
<td>MILL A</td>
<td>MILL B</td>
<td>MILL C</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>H.C. 1</td>
<td>H.C. 2</td>
<td>H.C. 3</td>
</tr>
<tr>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

**HOURLY CANE DELIVERY**

**TRANSPORT SECTOR**

**CONTRACTORS**

**MUSOLAS CONTRACT**

**BUNDLES**

**TONNES**

**PER HR**

**PER HP**

---

**DETAILS**

- **H.C. 1**
- **H.C. 2**
- **H.C. 3**
- **H.C. 4**
- **H.C. 5**
- **H.C. 6**
- **H.C. 7**
This Appendix is a sample sheet of the MSC's Hourly Waiting Times Sheet. The terms used in this sheet are:

1. DB MILL "A" - Average waiting time of Double Bundle trailers using weighbridge A, WBA.
2. SB MILL "A" - Average waiting time of Single Bundle trailers using weighbridge A, WBA.
3. N/E MILL "A" - Average waiting time of Nuclear Estate (Loose cane or Basket) trailers using weighbridge A, WBA.

The other average waiting time terms indicated on this sheet are for the units which use weighbridge B, WBB. The term used are similar to those using weighbridge A.
<table>
<thead>
<tr>
<th>TIME</th>
<th>W</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>06 - 07 HRS</td>
<td>21</td>
<td>19</td>
<td>19</td>
<td>21</td>
<td>27</td>
</tr>
<tr>
<td>07 - 08 HRS</td>
<td>14</td>
<td>32</td>
<td>21</td>
<td>31</td>
<td>64</td>
</tr>
<tr>
<td>08 - 09 HRS</td>
<td>79</td>
<td>31</td>
<td>13</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>09 - 10 HRS</td>
<td>112</td>
<td>32</td>
<td>27</td>
<td>92</td>
<td>56</td>
</tr>
<tr>
<td>10 - 11 HRS</td>
<td>87</td>
<td>14</td>
<td>9</td>
<td>80</td>
<td>31</td>
</tr>
<tr>
<td>11 - 12 HRS</td>
<td>78</td>
<td>34</td>
<td>17</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>12 - 13 HRS</td>
<td>13</td>
<td>23</td>
<td>50</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>13 - 14 HRS</td>
<td>18</td>
<td>25</td>
<td>23</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>14 - 15 HRS</td>
<td>90</td>
<td>31</td>
<td>12</td>
<td>67</td>
<td>47</td>
</tr>
<tr>
<td>15 - 16 HRS</td>
<td>69</td>
<td>30</td>
<td>21</td>
<td>57</td>
<td>30</td>
</tr>
<tr>
<td>16 - 17 HRS</td>
<td>34</td>
<td>15</td>
<td>16</td>
<td>43</td>
<td>24</td>
</tr>
<tr>
<td>17 - 18 HRS</td>
<td>115</td>
<td>21</td>
<td>13</td>
<td>81</td>
<td>24</td>
</tr>
<tr>
<td>18 - 19 HRS</td>
<td>40</td>
<td>17</td>
<td>22</td>
<td>59</td>
<td>121</td>
</tr>
<tr>
<td>19 - 20 HRS</td>
<td>70</td>
<td>18</td>
<td>20</td>
<td>42</td>
<td>21</td>
</tr>
<tr>
<td>20 - 21 HRS</td>
<td>75</td>
<td>33</td>
<td>21</td>
<td>47</td>
<td>35</td>
</tr>
<tr>
<td>21 - 22 HRS</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>22 - 23 HRS</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>23 - 24 HRS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 - 01 HRS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01 - 02 HRS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02 - 03 HRS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03 - 04 HRS</td>
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<td></td>
</tr>
<tr>
<td>04 - 05 HRS</td>
<td></td>
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</tr>
<tr>
<td>05 - 06 HRS</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
This Appendix contains listings of the program that were use in this study. The listings given are for:

1. A listing Cane Yard Simulation Program written in Turbo PASCAL Version 5.5. Program and procedure headings are given in bold form. Explanation of what a given procedure does are put in curly brackets,

2. A listing of FREQANA, a dBase III plus general purpose program that was developed to analyze the data collected, and

3. A listing of STATS. A dBase III plus program developed to for determination of mean and variance of the data gathered.
Program CaneyardSimulation (input, outPut);
USES Crt, Printer;
{This is the program heading}

const sizeRU = 500;

Type List = Array[1..500] of real;

Var a:list; c, i, j, k, NBA, RNBA, NBB, RNBB, NBD, NBDGC, RNBDDGC, NBDST, RNBDST, ONBA, ONBB, ONBDGC, ONBDST :integer;MillA, MillB, TATBK, TABK, TBBK, TBTBK, TBD, TTBK, TOTHYDA, NWGC, MAI, MBI, STSTOCK, GCSTOCK, CRA, CRB, TIME, TSTOCK, ETIME:real; AMILL, TMILLAB, MILLAB, RSTOCK, MillT, WBA, WBB, WST, ONWGC, WGC: real; f, g, h:file;

{This is a procedure that generates the random numbers from the system clock}
begin
randomize;
for i := 1 to sizeRU do
A[i] := random;
end;{end procedure}
Procedure Milling (Var MillA, MillB : Real; Var A : list);
{Sampling of mill-A and MillB milling requirements}
type
  natural = 0..Maxint;
  realfile = File
  of real;
  mill = array[1..24] of real;
  upa = array[1..24] of real;
  upb = array[1..24] of real;
Var
  i, size : natural;
  f : realfile;
  mil, Urnda, UrndB : real;
  mi : mill;
  ai : upa;
  bi : upb;
begin
  Assign(f, 'a:fread');
  reset(f);
  I := 1;
  while not eof(f) do
    begin
      read(f, mil, Urnda, Urndb);
      mi[i] := mil;
      ai[i] := Urnda;
      bi[i] := Urndb;
      writeln(mil:8:1, Urnda:8:3, Urndb:8:3);
      i := i + 1;
    end; {end while for reading the file}
begin
  I := 1;
  while i < 25 do
    begin
      writeln(mi[i]:8:1, ai[i]:8:3, bi[i]:8:3);
      i := i + 1;
    end; {end while}
end;
begin
  i := 1;
  while ai[i] <= A[1] do
    begin
      MillA := mi[i];
      i := i + 1;
    end; {end while}
end;
begin
  i := 1;
    begin
      MillB := mi[i];
      i := i + 1;
    end;
end; {end while}
close(f);
end;
end; {end procedure}

Procedure DELIVERY (var TIME : real; var NBA, RNBA, NBB, RNBB, NBD, NBDC, RNBDGC, NBDST, RNBDST: INTEGER; var A : List);
{This procedure simulates the arrival of units at the weighbridge from the field for all units on an hourly basis}

Type
Natural = 0..Maxint;
realfile = File of real;
H = Array[1..24] of real;
LCA = Array[1..24] of real;
LCB = Array[1..24] of real;
BC = Array[1..24] of real;

Var
j, size : natural;
g:realfile;
NAK, NBK, NB: INTEGER;
Hour, TATBK, TABK, ABK, TBTBK, TBBK, BBK, TTBD, TBD, ABBD : REAL;
HR:H; MABK:LCA; MBBK:LCB; MABBD:BC;

Begin
j := c;
Assign(g, 'a:mhdread');
reset(g);
seek(g, FilePos(g) + j);
writeln('Position now is: ', FilePos(g));
Read(g, Hour, abk, bbk, abbd);
writeln('Hour ', abk, 'bbk', 'abbd');
writeln(hour:8:2, abk:8:2, bbk:8:2, abbd:8:2);
TIME := HOUR;
writeln('TIME = ', TIME:8:2);
if abk > 0 then
begin
TATBK := 0;
NAK := 0;
I := 3;
writeln('abk = ', abk:2:3);
Repeat
TABK := (-1/abk)*ln(A[I]);
TATBK := TATBK + TABK;
NAK := NAK + 1;
I := I + 1;
Until TATBK >= 1;
NBA := RNBA + NAK - 1;
writeln('NBA = ', NBA:2);
end
else
nba := 0;

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{This is the starting point of Baskets Arrival for HYDB}
{writeln('bbk = ', bbk:2:3); }
if bbk > 0 then
  begin
    TBBK := 0;
    NBK := 0;
    I := 40;
    Repeat
      TBBK := (-1/bbk)*LN(A[I]);
      TBBK := TBBK + TBBK;
      NBK := NBK + 1;
      I := I + 1
    Until TBBK >= 1;
    NBB := RNBB + NBK - 1;
    writeln('NBB = ',NBB:2);
  end
else
  nbb := 0;
{This is Bundled Cane Arrival sampling loop - Self tipping and ordinary trailers}
{writeln('abbd = ',abbd:2:3); }
if abbd > 0 then
  begin
    TTBD := 0;
    NB := 0;
    I := 70;
    Repeat
      TBD := (-1/abbd) * ln(A[I]);
      TTBD := TTBD + TBD;
      NB := NB + 1;
      I := I + 1;
    until TTBD >= 1;
    NBD := NB - 1;
  end
else
  nbd := 0;
{Calculations for determining the number of Self-tipping and non Self-tipping
trailers at this point}
  NBDGC := RNBDGC + ROUND(0.8*NBD);
  NBDST := RNBDST + ROUND(0.2*NBD);
{writeln('NBD = ',NBD:2,',','NBDGC = ',NBDGC:2,',','NBDST = ',NBDST:2);} close(g);
end;

Procedure GENORVALUES (var NBA, NBB, NBDGC, NBDST, ONBA, ONBB,
ONBDGC, ONBDST : integer);
Begin
  ONBA := NBA;
  ONBB := NBB;
  ONBDGC := NBDGC;
  ONBDST := NBDST;
end;{end procedure}
Procedure LCUnloadingA (var MillA, MAI, WBA : REAL; var NBA : integer; Var A : list);
Const
  MHYDA = 27.53683; {Mean number of units that can be unloaded by HYDA in an hour}
  PLBK = 6.5; {Payload of a single basket unit}
Var
  TOTHYDA, THYDA, ITHYDA, WAI, WAO : Real;
  NBAU : integer;
begin
  TOTHYDA := 0;
  WAI := 0;
  NBAU := 0;
  ONBA := NBA;
  MAI := MillA;
  If (MillA > 0) and (NBA > 0) then
  begin
    I := 100;
    repeat
      NBA := NBA - 1;
      NBAU := NBAU + 1; {basket units unloaded by HYDA}
      THYDA := (-1/mhyda)*ln(A[I]);
      MillA := MillA - PLBK;
      TOTHYDA := TOTHYDA + THYDA;
      WAI := WAI + TOTHYDA;
      {WRITE(THYDA:8:3)};
      {WRITELN(' NBA = ',NBA:2:2)};
      I := I + 1;
    until (tothyda >= 1) OR (NBA <= 0) OR (MillA <= 0);
    { write('TOTHYDA = ',tothyda:2:3,' Hrs.',',',', NBA = ',NBA:2:2,' MillA = ',
      milla:2:2, ', NBAU = ', NBAU:2:2)};
    {WRITELN;};
    ITHYDA := 1-TOTHYDA;
    WAO := NBA;
    WBA := ROUND(WAO + WAI)*60/ONBA;
  end {end if}
  else
    WBA := 0;
  if (MAI = 0) and (NBA > 0) then
    WBA := 60;
  END; {end of procedure}

Procedure STUnloading (var STSTOCK, WST:real;var NBDST : integer; Var A : List);
const
  PLST = 6.00; {Pay load of a single unit}
  CSTOCK = 400; {Critical stocking level for the Self-tipping stocking area}
Var
  TOTST, TST, WTI, WTO : real;
  NBDSTU:integer;
Begin
{writeln('Original NBDST = ', NBDST:2);} 
ONBDST := NBDST;
NBDSTU := 0;
WTI := 0;
TOTST := 0;
I := 150;
while (TOTST < 1) AND (NBDST > 0) AND (STSTOCK < CSTOCK) do
Begin
NBDST := NBDST - 1;
NBDSTU := NBDSTU + 1;
TST := (-1/8.571) * ln(A[I]);
TOTST := TOTST + TST;
WTI := WTI + TOTST;
STSTOCK := STSTOCK + PLST;
I := I + 1;
end;{end while}
{writeln('TOTST = TOTST:2:2, 'NBDSTU = NBDSTU:2, 'NBDST = 
NBDST:2,'STSTOCK = STSTOCK:2:2);} 
WTO := NBDST;
WST := ROUND(WTI + WTO)*60/ONBDST;
end;{end procedure }

Procedure STSFeedingA (var MillA, STSTOCK : real);
Const
RNF = 1;{RNF:- Rainfall factor, equal to 1 throughout this procedure}
Begin
{writeln('MillA = ', milla:2:2, 'STSTOCK = ', ststock:2:2);} 
If (STSTOCK > MillA ) and (MillA > 0) and (RNF = 1) then
begin
STSTOCK := STSTOCK - MillA;
MillA := 0;
{writeln('MillA = ', MillA:2:2,'STSTOCK = ',STSTOCK:2:2);} 
end;{end if}
if (STSTOCK > 0) and (MillA > STSTOCK) then
begin
MillA := MillA - STSTOCK;
STSTOCK := 0;
{writeln('MillA = ', MillA:2:2, 'STSTOCK = ', STSTOCK:2:2);} 
end;{end if}
end;{end procedure}

Procedure LCUnloadingB (var MillB, MBI, WBB : real; var NBB : Integer; Var A : List);
Const
MHYDB = 27.53683;
PLBK = 6.5;
var
TOTHYDB, THYDB, ITHYDB, WBI, WBO : Real;
\begin{verbatim}
begin
TOTHYDB := 0;
WBI := 0;
ONBB := NBB;
MBI := MillB;
If (MillB > 0) AND (NBB > 0) then
begin
   i := 151;
repeat
   NBB := NBB - 1;
   THYDB := (-1/MHYDB)*ln(A[i]);
   MillB := MillB - PLBK;
   TOTHYDB := TOTHYDB + THYDB;
   WBI := WBI + TOTHYDB;
   {Write(THYDB:8:3);
    writeln(NBB:3);}
   i := i+1;
until (TOTHYDB > 1) OR (NBB <= 0 ) OR (MillB <= 0);
{write('TOTHYDB = tothydb:2:3, 'NBB = nbb:2, 'MillB = MillB:2:2);
 writeln; }
ITHYDB := 1-TOTHYDB;
{writeln('ITHYDB = ', ITHYDB:2:3);
 writeln('MBI = ', MBI:6:2})
WBO := NBB;
WBB := ROUND((WBO + WBI)*60)/ONBB;
end
else
    WBB := 0;
if (MBI = 0) and (NBB > 0) then
    WBB := 60;
end;
\end{verbatim}

Procedure NumberofWorkingGCS (var NWGC:real; Var Arlist);
type
  Natural = 0..Maxint;
  Realfile = File of real;
  GC = Array[1..5] of Real;
  URNDGC = Array(1..5) of real;
Var
  i, size : natural;
  h : RealFile;
  WGC, RNDGC : real;
  N : GC;
  RU : URNDGC;
begi
  Assign(h, 'ainwgcread');
  Reset(h);
  i := 1;
  while not eof(h) do
\end{verbatim}
begin Read(h, WGC, RNDGC);
N[i] := WGC;
RU[i] := RNDGC;
i := i + 1;
end; {end while}
close(h);

begin Assign(h, 'a:nwgcread');
reset(h);
i := 1;
begin
NWGC := N[i] + 1;
i := i + 1;
if NWGC < 3 then
NWGC := NWGC + 1; {Data collected was for unloading cranes only}
{writeln('Nwgc = ',nwgc:2:0);}
ONWGC := NWGC;
end;
close(h)
end; {end while}
end; {end procedure}

Procedure Stockpiling (var GCSTOCK, NWGC, WGC:real; var NBDGC : integer; var A : list);
Const
TVOLA = 5500;
PLGC = 6.00;
MGCU = 13.514;
Var
TGC, TOTGC, WI, WGO, WGI : real;
Begin
{writeln('NBDGC = ', NBDGC:2, 'GCSTOCK = ', GCSTOCK:2:2);}
If GCSTOCK < TVOLA then
begin
I := 300;
NWGC := NWGC - 1;
WGI := 0;
while (NWGC > 0) and (NBDGC > 0) do
begin
NWGC := NWGC - 1;
TOTGC := 0;
WI := 0;
repeat
NBDGC := NBDGC - 1;
TGC := (-1/MGCU) * ln(A[I]);
GCSTOCK := GCSTOCK + PLGC;
TOTGC := TOTGC + TGC;
WI := WI + TOTGC;
end;
end; {end while}
\begin{verbatim}
I := I + 1;
Until (TOTGC >= 1) or (NBDGC = 0) or (GCSTOCK >= TVOLA);
\{ writeln('TOTGC = ', TOTGC:2:2, ' NBDGC = ', NBDGC:2,' NWGC = ',NWGC:2:0, ' GCSTOCK = ',GCSTOCK:2:2);} 
WGI := WI + WGI
end;\{end while\}
WGO := NBDGC;
WGC := ROUND(WGO + WGI)*60/ONBDGC;
end;\{end if\}
end;\{end procedure\}

Procedure STPFeeding (var GCSTOCK, MillA, MillB, NWGC : real);
var
   MillAB:real;
Begin
   MillAB := MillA + MillB;
   \{ writeln('MillA = MillA:2:2, 'MillB = MillB:2:2,' MillAB = MillAB:2:2);\}
   If (GCSTOCK > MillAB) and (MillAB > 180) and (NWGC > 0) then
      Begin
         MillA := 0;
         MillB := 0;
         GCSTOCK := GCSTOCK - MillAB;\{A Grab has been fitted\}
         NWGC := NWGC - 1;
      end;\{ end if\}
   If (GCSTOCK > MillAB) and (MillAB < 180) then 
      begin
         MillA := 0;
         MillB := 0;
         GCSTOCK := GCSTOCK - MillAB;
      end;\{end if\}
   If (GCSTOCK < MillAB) and (MillA < MillB) and (GCSTOCK > MillB) then
      begin
         MillB := 0;
         MillA := MillAB - GCSTOCK;
         GCSTOCK := 0;
      end;\{end if\}
   If (GCSTOCK < MillAB) and (MillA > MillB) and (GCSTOCK > MillA) then
      begin
         MillA := 0;
         MillB := MillAB - GCSTOCK;
         GCSTOCK := 0;
      end;\{ end if\}
   If (MillAB > GCSTOCK) and (MillA < MillB) and (GCSTOCK < MillB) then
      begin
         MillB := MillB - GCSTOCK;
         GCSTOCK := 0;
      end;\{end if\}
   If (MillAB > GCSTOCK) and (MillA > MillB) and (GCSTOCK < MillA) then
      begin
         MillA := MillA - GCSTOCK;
         GCSTOCK := 0;
      end;
\end{verbatim}
**Procedure TOTALSTOCK (Var GCSTOCK, STSTOCK, TSTOCK : real);**
{This is a procedure that calculates the total stocking level of cane in the yard at the end of every hour of milling.
Begin
   TSTOCK := GCSTOCK + STSTOCK
{end procedure}

**Procedure TRUCKSUPDATE (var RNBA, RNBB, RNBDGC, RNBDST : integer);**
{This procedure updates the number of units that were not unloaded and puts them into queues for unloading during the next hour, such units are ahead of newly arriving units and are therefore unloaded first}
begin
   RNBA := NBA;
   RNBB := NBB;
   RNBDGC := NBDGC;
   RNBDST := NBDST;
{writeln('RNBA = ',RNBA:2,' RNBB = ',RNBB:2,' RNBDGC = ',RNBDGC:2,' RNBDST = ',RNBDST:2);}
end;{end procedure}

**Procedure PRINTHEAD (var TIME, MAI, MillA, MBI, MillB, GCSTOCK, STSTOCK, TSTOCK, RSTOCK, NWGC, WBA, WBB, WST, WGC : real; RNBA, RNBB, RNBDGC, RNBDST, ONBA, ONBB, ONBDGC, ONBDST:integer);**
{This procedure prints the selected output parameters after every 24 hours of program execution its output is directed to the printer}
Var
   Lst :Text;
Begin
   Assign(Lst, 'a:out');
   Rewrite(lst);
   {Append(lst);}
   writeln(lst);
   writeln Ost,' TIME':8, 'MillA':9, 'MAI':8, 'MillB':12, 'MBI':9, 'GCSTOCK':12, 'STSTOCK':9, 'TSTOCK':10, 'RSTOCK':10, 'NWGC':8, 'ONBA':7, 'RNBA':8, 'ONBB':8, 'RNBB':8, 'ONBDGC':8, 'RNBDGC':8, 'ONBDST':7, 'RNBDST':8, 'WBA':10, 'WBB':8, 'WST':8, 'WGC':8);
Close(lst);
end;{end procedure}

**Procedure PRINTOUT1 (var TIME, MillA, MAI, MillB, GCSTOCK, STSTOCK, TSTOCK, RSTOCK, NWGC, WBA, WBB, WST, WGC : real; var RNBA, RNBB, RNBDGC, RNBDST, ONBA, ONBB, ONBDGC, ONBDST:integer);**
{This procedure sends the output to the printer for the selected hourly output parameters for the yard operations if the output is directed to the printer}
var
   Lst : Text;
Begin
Assign(List, 'a:out');
Append(List);
writeln(List, TIME:8:2, MillA:8:2, MillB:10:2, GCSTOCK:10:2, STSTOCK:10:2, TSTOCK:10:2, RSTOCK:10:2, NWGC:9:0, ONBA:7, RNBA:8, ONBB:8, RNBB:8, ONBDGC:8, RNBDGC:8, ONBDST:7, RNBDST:8, WBA:10:0, WBB:8:0, WST:8:0, WGC:8:0);
close(List);
end;{end procedure}

Procedure ELAPSED TIME (var TIME, ETIME, RTIME : real);
{A procedure that up-dates the elapsed time as the day's operations advance}
begin
If TIME > 6.00 then
begin
ETIME := TIME - 6;
rtime := 24 - time
end {end if}
else
ETIME := TIME + 18;
RTIME := 24 - ETIME;
{ writeln('ETIME = ', ETIME:2:2, 'RTIME = ', RTIME:2:2); }
end;{end procedure}

Procedure DESPARK (var RSTOCK, AMILL, MILLT : real; MAI, MBI, RTIME, ETIME : real);
{A procedure that determines when parking of cane units can be done without the mills running out of cane until the following day at 6.00 hours. It is based on a day's average milling for both mills}
begin
MillT := (MAI + MBI) + MILLT;
AMILL := MILLT/ETIME;
RSTOCK := AMILL*RTIME;
end;{end procedure}

{MAIN PROGRAM STARTS}
begin
Initialize (STSTOCK, GCSTOCK, MILLT, AMILL, RSTOCK, RNBA, RNBB, RNBDGC, RNBDST);
PrintHead (TIME, MAI, MBI, MillA, MillB, GCSTOCK, STSTOCK, TSTOCK, RSTOCK, NWGC, WBA, WBB, WST, WGC, RNBA, RNBB, RNBDGC, RNBDST, ONBA, ONBB, ONBDGC, ONBDST);
Writeln('Input the number of days to simulate')
Readln(n);
For k := 1 to n DO
Begin
  c := 0;
  MillT := 0;
  REPEAT
    rng(A);
end;
Milling (MillA, MillB, A);
Delivery (TIME, NBA, RNBA, NBB, RNBB, NBD, NBDGC, RNBDGC, NBDST, RNBDST, A);
GENORVALUES (NBA, NBB, NBDGC, NBDST, ONBA, ONBB, ONBDGC, ONBDST);
LCUnloadingA (MillA, MAI, WBA, NBA, A);
STUnloading (STSTOCK, WST, NBDST, A);
STSPeedingA (MillA, STSTOCK);
LCUnloadingB (MillB, MBI, WBB, NBB, A);
NumberOfWorkingGCS (NWGC, A);
Stockpiling (GCSTOCK, NWGC, WGC, NBDGC, A);
STPFeeding (GCSTOCK, MillA, MillB, NWGC);
TOTALSTOCK (GCSTOCK, STSTOCK, TSTOCK);
TRUCKSUPDATE (RNBA, RNBB, RNBDGC, RNBDST);
ELAPSEDTIME (TIME, ETIME, RTIME);
DESPARK (RSTOCK, AMILL, MILLT, MAI, MBI, RTIME, ETIME);
PRINTOUT1 (TIME, MillA, MAI, MillB, MBI, GCSTOCK, STSTOCK, TSTOCK, RSTOCK, NWGC, WBA, WBB, WST, WGC, RNBA, RNBB, RNBDGC, RNBDST, ONBA, ONBB, ONBDGC, ONBDST);
c := c + 4;
Until c = 96;
end;{end for - k}
end;{end for}
end.{end CaneYardSimulation}
FREQANA PROGRAM LISTING

store " " to infile
store " " to outdata
store " " TO Fname
STORE 0 TO FRQ
CLEAR
@ 10,10 SAY "Input name of File to be analyzed" GET INFILE
@ 11,10 SAY "Input name of output file " GET OUTDATA
@ 12,10 SAY " Input name of Field to be analyzed" GET FNAME
READ
select 1
use &infile
select 2
use &outdata
GO TOP
DO WHILE .NOT. EOF0
STORE LCLASS TO LOWER
STORE UCLASS TO UPPER
SELECT 1
COUNT FOR &FNAME> = LOWER .AND. &FNAME< UPPER TO FRQ
SELECT 2
REPLACE FREQ WITH FRQ
SKIP
ENDDO
SUM FREQ TO POPTOT
REPLACE ALL RFREQ WITH FREQ/POPTOT
GO TOP
STORE 0 TO CFRQ
DO WHILE .NOT. EOF0
CFRQ = CFRQ + RFREQ
REPLACE CUMFREQ WITH CFRQ
SKIP
ENDDO
LIST TO PRINT
CLEAR ALL
*-------FIND MEAN
STORE 0 TO M
STORE 0 TO N
STORE 0 TO A
SUM SLF FOR SLF >0 TO A
COUNT FOR SLF >0 TO N
m=A/N

*-------FIND VARIANCE
GO TOP
STORE 0 TO SD
STORE 0 TO CUM
DO WHILE .NOT. EOF()
CUM=SLF^2+CUM
SKIP
ENDDO
SD=(CUM-N*M^2)/(N-1)
SET PRINT ON
disp memo to print
set print off

Note: SLF appearing in the above program could be altered to any field name in a dBase data file.
This Appendix presents the flow charts that were constructed for the Simulation Program development.
Appendix 4.1 Loose Cane Trailers - Hydro-Loaders Subsystem

START

Initialize counters for the Hour's operations

Simulate Loose cane units arrivals for the Hour and update the arrival counter

Simulate Loose cane units unloading operation for the Hour and Mills' feeding operation

Update counters and variables for the following:

1. Number (units) left unloaded
2. Milling rate value remaining after feeding the Mill with cane from the Loose cane units
Appendix 4.2 Self-tipping Trailers Subsystem

1. Initialize counters for the Hour’s operations

2. Simulate Self-tipping trailers arrivals for the Hour

3. Simulate Self-tipping trailers unloading operations for the Hour

4. Simulate Mill feeding operations (Mill A) with cane from area, A1

5. Update the following counters:
   1. Cane in stockpile (Area A1)
   2. Numbers of units not unloaded
   3. Mill A, i.e., remaining Mill A mill requirement after feeding operations
Appendix 4.3 Ordinary bundle trailers - Gantry cranes Subsystem

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Initialize counters for the Hour's operations

Simulate bundle cane arrivals for the Hour

Simulate bundle cane unloading by the Gantry cranes

Simulate Mill feeding operation with cane from the stockpile/trailers:
1. Bridle Mill feeding
2. Grab Mill feeding
3. Front-End Loader Mill feeding

Update the following counters:
1. Cane in stockpile, i.e., Area A2
2. Number of units not unloaded at the end of the Hour
3. Mill requirement for both Mills

END
LIST OF REFERENCES


