BPJ 420

Provision of loading docks and parking spaces for goods vehicles at developments

by

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Executive summary

The provision of a sufficient number of loading docks and parking spaces for goods vehicles is an important consideration at developments. The purpose of this study is to evaluate current queuing models that are used for this purpose.

The problem that was identified is that existing queuing models are based on the assumption that service times follow an Exponential distribution while a Log-Normal distribution is more appropriate. The use of the Exponential distribution results in an overestimation of the required number of loading docks and parking spaces.

Service time distributions were evaluated during the study and use was made of a simulation model to estimate the required number of loading docks and service times. The conclusion of the study is that existing approaches overestimate the required number of loading docks and parking spaces at developments.

Table of Contents

List of Figures 4

List of tables 5

Chapter 1. INTRODUCTION 6
1.1. BACKGROUND 6
1.2. PROBLEM STATEMENT 7
1.3. PROJECT AIM AND OBJECTIVES 7
1.4. PROJECT SCOPE 8
1.5 DELIVERABLES AND PROJECT PLAN 9
1.5.1. ACTIVITIES, TASKS AND DELIVERABLES 9
1.6. RESOURCES 11
1.7. BUDGET 11

Chapter 2. LITERATURE REVIEW 12
2.1. SAMPLE SIZE 12
2.2. SERVICE TIME DISTRIBUTION 14
2.3. ARRIVAL TIME DISTRIBUTION 18
2.4. QUEUING THEORY 18
2.5. SIMULATION 20
2.6.CHAPTER SUMMARY 24

Chapter 3. DATA COLLECTION 25
3.1. SITE DEVELOPMENT PLANS AND GOOGLE MAP PICTURES 25
3.2. SAMPLE SIZE REQUIREMENTS 26
3.3. TIME STUDIES 27
3.4. QUESTIONAIRE 28
3.5. CHAPTER SUMMARY 29

Chapter 4. DATA ANALYSIS 30
4.1. OVERVIEW OF THE DATA 30
4.2. BEST FITTED DISTRIBUTION 32
4.2.1. Best fitted distribution for site 1 32
4.2.2. Best fitted distribution for site 2 33
4.2.3. Best fitted distribution for site 3 34
4.2.4. Best fitted distribution for site 4 36
4.2.5. Best fitted distribution for site 5 37
4.3. CHAPTER SUMMARY 39

Chapter 5. SIMULATION MODEL AND QUEUING THEORY 40
5.1. INTRODUCTION 40
5.2. SIMULATION MODEL 41
5.3. QUEUING SYSTEM 42
5.3. VERIFICATION OF SIMULATION MODEL 43
5.3.1. Verification of simulation model with exponential distributions 43
5.3.2. Verification of simulation model with normal distributions 43
5.3.3. Verification of simulation model with Log Normal distributions 44
5.4. CHAPTER SUMMARY 45

Chapter 6. OUTCOME OF RESEARCH 46

Chapter 6. CONCLUSION AND RECOMMENDATIONS 47

6.1. CONCLUSION 47
6.2. RECOMMENDATIONS 47
7. REFERENCES 48
Appendix A 51
Appendix B 56
Appendix C 60
Appendix C.1: Time studies of the five sites 60
Appendix C.2: Service times and the different distributions 65
Appendix C.3: Filled- in question lists for the five sites 70
Appendix D 75
Appendix E: 80
Appendix E.1: Random number generator coding in Visual Basics 80
Appendix E.2: Main program coding in Visual Basics 83
Appendix E.3: Load data coding in Visual Basics 84
Appendix E.4: Simulation model coding in Visual Basics 85
Appendix E.5: Queuing system coding in Visual Basics 88
Appendix F: 90

List of Figures

FIGURE 1: SAWTOOTH DOCK [4] 13
FIGURE 2: INSIDE/OUTSIDE DOCK [4] 14
FIGURE 3: OPEN DOCKS [4] 14
FIGURE 4: BELL- SHAPED CURVE FROM THE NORMAL DISTRIBUTION 15
FIGURE 5: A GRAPHICAL EXAMPLE FOR THE LOG-NORMAL DISTRIBUTION 15
FIGURE 6: THE EQUATION AND BASIC SHAPE OF THE EXPONENTIAL DISTRIBUTION [10] 16
FIGURE 7: DEVELOPMENTS IN CENTURION 25
FIGURE 8: LOWER BOUND/MEAN/UPPER BOUND (Y-AXIS) VERSUS SAMPLE SIZE OF VEHICLES (X-AXIS) 26
FIGURE 9: SERVICE TIME AVERAGES AND STANDARD DEVIATIONS AT THE VARIOUS SITES 30
FIGURE 10: THE NORMAL, LOG NORMAL AND EXPONENTIAL SERVICE TIME DISTRIBUTIONS FITTED TO THE DATA FOR SITE 1 32
FIGURE 11: THE NORMAL, LOG NORMAL AND EXPONENTIAL SERVICE TIME DISTRIBUTIONS FITTED TO THE DATA FOR SITE 2 33
FIGURE 12: THE NORMAL, LOG NORMAL AND EXPONENTIAL SERVICE TIME DISTRIBUTIONS FITTED TO THE DATA FOR SITE 3 35
FIGURE 13: THE NORMAL, LOG NORMAL AND EXPONENTIAL SERVICE TIME DISTRIBUTIONS FITTED TO THE DATA FOR SITE 4 36
FIGURE 14: THE NORMAL, LOG NORMAL AND EXPONENTIAL SERVICE TIME DISTRIBUTIONS FITTED TO THE DATA FOR SITE 5 38
FIGURE 15: THE FLOW OF THE CODING IN VISUAL BASICS 40
FIGURE 16: VERIFICATION OF SIMULATION MODEL WITH EXPONENTIAL DISTRIBUTIONS 43
FIGURE 17: VERIFICATION OF SIMULATION MODEL WITH NORMAL DISTRIBUTIONS 44
FIGURE 18: VERIFICATION OF SIMULATION MODEL WITH LOG NORMAL DISTRIBUTIONS 45
FIGURE 19: GANTT CHART FOR BPJ 410 AND BPJ 420 51
FIGURE 20: QUESTION LIST TEMPLATE 54
FIGURE 21: TYPICAL SIZE CLASSIFICATIONS FOR DELIVERY VEHICLES 55
FIGURE 22: SITE1 56
FIGURE 23: SITE2 56
FIGURE 24: SITE3 57
FIGURE 25: SITE4 58
FIGURE 26: SITE 5 59

List of tables

TABLE 1: BUDGET FOR PROJECT 11
TABLE 2: QUESTION LISTS SUMMARY 28
TABLE 3: STATISTICAL MEASURES FOR THE SERVICE TIMES AT THE DIFFERENT SITES 30
TABLE 4: AVERAGE MOVE-UP TIMES (IN MINUTES) OF THE FIVE SITES 31
TABLE 5: NEW CALCULATED RATIOS (%) FROM THE SIMULATION MODEL 46
TABLE 6: BASIC OBSERVATIONS TABLE FOR USE OF TIME STUDIES 52
TABLE 8: STANDARD NUMBER OF LOADING DOCKS AND PARKING SPACES 53
TABLE 7: DELIVERY VEHICLE TRIP GENERATION RATES AND SERVICE TIMES 53
TABLE 9: IRENE MALL (SITE 1) TIME STUDY 60
TABLE 10: BUILDER'S WAREHOUSE (SITE 2) TIME STUDY 61
TABLE 11: LIFESTYLE CENTRE (SITE 3) TIME STUDY 62
TABLE 12: MAKRO (SITE 4) TIME STUDY 63
TABLE 13: MALL @ REDS (SITE 5) TIME STUDY 64
TABLE 15: SERVICE TIMES AND THE DIFFERENT DISTRIBUTIONS AT IRENE MALL 65
TABLE 14: LOADING TIMES AT IRENE MALL 65
TABLE 16: LOADING TIMES AT BUILDER'S WAREHOUSE 66
TABLE 17: SERVICE TIMES AND THE DIFFERENT DISTRIBUTIONS AT BUILDER'S WAREHOUSE 66
TABLE 18: LOADING TIMES AT LIFESTYLE CENTRE 67
TABLE 19: SERVICE TIMES AND THE DIFFERENT DISTRIBUTIONS AT LIFESTYLE CENTRE 67
TABLE 20: LOADING TIMES AT MAKRO 68
TABLE 21: SERVICE TIMES AND THE DIFFERENT DISTRIBUTIONS AT MAKRO 68
TABLE 22: LOADING TIMES AT MALL @ REDS 69
TABLE 23: SERVICE TIMES AND THE DIFFERENT DISTRIBUTIONS AT MALL @ REDS 69
TABLE 24: VERIFICATION OF SIMULATION MODEL WITH NORMAL DISTRIBUTIONS 90
TABLE 25: VERIFICATION OF SIMULATION MODEL WITH EXPONENTIAL DISTRIBUTIONS 90
TABLE 26: VERIFICATION OF SIMULATION MODEL WITH LOG NORMAL DISTRIBUTIONS 91

Chapter 1. INTRODUCTION

1.1. BACKGROUND

Traffic and transport engineering is an essential application of technology to the operation of moving goods or people from one place to another. It is a part of most people's daily routine, whether it is delivering goods, going to school, picking-up necessities or travelling afar. Traffic and transport engineering is partly responsible for connecting businesses and improving communication.

Mechanisms for entering or exiting queuing systems are a part of everyday life with the aim to regulate the accessibility of developments (Warehouses, Shopping centres, Offices and Distributions centres). Smooth traffic flow that is hindered at delivery areas result in ineffective queuing spaces and service rates. The project will be focused on the observation of diverse delivery areas, the theory of queuing and finding solutions for problems that occur.

1.2. PROBLEM STATEMENT

Standards for the number of loading docks and parking spaces are currently available. These standards were developed on the basis of the M/M/s queuing system. This system implies that arrivals follow a Poisson distribution while service times follow an Exponential Distribution

The M/M/s model could lead to a significant overestimation of queue lengths when the service times are not exponentially distributed. An underestimation or overestimation of the required number of loading docks and parking spaces could have serious consequences and would lead to an unsuccessful design.

The underestimation of the number of loading docks and parking spaces would lead to long waiting times and delays. These delays may lead to unsatisfied customers or products not delivered on time or external delivery companies whom cannot finish their daily schedules. A deficient delivery area has a negative influence on finance, service provision, time and professionalism.

On the other hand, however, the overestimation of the number of loading docks and parking spaces would result in the efficient utilisation of land area and high costs.

1.3. PROJECT AIM AND OBJECTIVES

The aim of the project is to investigate queuing systems that were used to develop standards for the provision of loading docks and parking spaces at developments.

The specific objectives of the study are:

1. Undertake observations to determine whether service times at loading docks follow the exponential distribution or whether another distribution should be used.

2. Develop new standards for the number of loading docks and parking spaces based on a more realistic service time distribution.
3. A simulation model was used during the study for developing the new standards. A further objective of the study was to verify this model.

1.4. PROJECT SCOPE

The design of loading docks and overflow parking depend on a number of factors. These are:

a) Delivery vehicle trip generation rates;
b) Queuing system to determine queue lengths; and
c) Geometric design of loading and parking areas.

The scope of this project excludes the estimation of the delivery vehicle trip generation rates as well as the geometric design of the loading and parking areas.

1.5 DELIVERABLES AND PROJECT PLAN

1.5.1. ACTIVITIES, TASKS AND DELIVERABLES

The project deliverables of the project is the development of new standards for the determination of the number of loading docks and parking vehicles for delivery vehicles at development.

A detailed time description of the project plan is provided in Appendix A in the form of two Gantt charts. The activities, tasks and resulting deliverables are as follows:

1. Select developments for survey
2. Undertaken observations of service rates

    2.1. Record sample data on parking and loading times. Start with visiting delivery areas at different sites and observed activity times. Obtaining additional data through contacting management of the sites. Questionnaires and time studies will be used to obtain the required information.

    Deliverable: Successfully completed

    2.2. Investigation of practices at the different sites by visiting the sites.

    Deliverable: Key practices

    2.3. The identification of specific problems that occur and possible improvements at the sites.

    Deliverable: Possible improvements and gaps

3. Data analysis

    3.1. Find the best fitted distribution for the observed data.

Deliverables: Finding a suitable distribution and motivate the method used

4. Evaluation

4.1. Obtain a simulation model that can be used for the analysis of queue lengths at loading docks.

Deliverable: Simulation model

4.2. Verify the simulation model through comparison with queuing theory.

Deliverable: Verification of simulation model

5. Undertake analysis

5.1. Undertake analysis to determine new standards for determining the number of loading docks and parking spaces

Deliverable: Development of new standards

6. Recommendations

6.1. Proposed improvements to existing information.

Deliverables: Process flow analysis

1.6. RESOURCES

The following assets are necessary for effective operation of the project:

- Stopwatch: To take time for the time studies.
- Vehicle: For transportation to and from different developments.
- Stationery: To record times.
- Computer and printer
- Internet
- Books, journals and other literature on queuing theory, traffic simulation etc.
- Industrial Engineering knowledge
- Miss. E van Wyk (Project leader)
- Dr. SC van As (Traffic engineer)

1.7. BUDGET

An estimation of the budget required for the project:

Table 1: Budget for project

Expenses for the project	**Amount (in Rand)**
Stationary	R 80
Telephone and Cell phone	R 280
Research and internet	R 350
Printing and binding	R 800
Transport	R 1000
Watch	R 150
TOTAL	**R 2660**

Chapter 2. LITERATURE REVIEW

An overview is provided in this chapter of the statistical methods and queuing models that were used during the project. These methods include those aimed at establishing the most appropriate statistical distribution for modelling the service time distributions.

2.1. SAMPLE SIZE

Before the commencement of observations of service times, it was necessary to determine the minimum sample size. Observations of the service times are a costly and time-consuming process and the number of samples had to be restricted to the minimum due to the limited resources that was available during the project.

The sample size requirements were determined by using the Confidence Interval for the mean of the service times based on the student's t-distribution. The confidence intervals for the standard deviation and other parameters of the service time distributions were not investigated during the study.

The confidence interval (CI) is used to represent the consistency of an approximation and it is an interval estimation of a population parameter [1].The confidence level is the probability associated with the confidence interval which is the probability that the true parameter would be in the interval.

The *t*-distribution is an incessant probability distribution that is used when calculating a distributed population's mean where the sample size is small (Dodge, 2003). The t distribution is the ratio of more than one independent random variable.

A graph can be used to estimate what the sample size should be with the Lower bound/Mean/Upper bound against the Sample size of vehicles. For this purpose, the following equation

[1]Adapted from: (CNX, 2007) and (KnowledgeHills, 2010). Referenced in Chapter 4.1 and 4.2

[2] is used for determining the Confidence interval (Dodge, 2003) for the sample mean:

$$C.I = \bar{X} \pm t_{\frac{\propto}{2}} \frac{S}{\sqrt{n}} \quad (1)$$

Where $\bar{X}$ = the sample mean

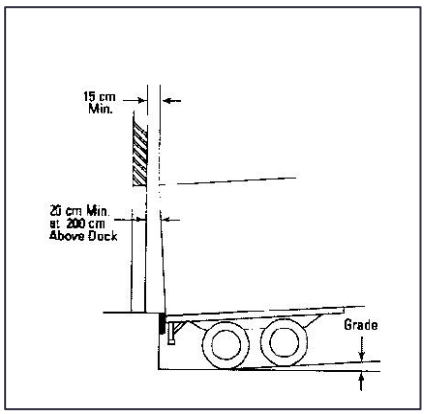
S = the sample standard deviation

$t_{\frac{\propto}{2}}$ = the t distribution value for the desired confidence level α

The standard deviation provides an indication of the degree to which service times vary from the mean [3]. A low standard deviation (Dodge, 2003) shows that the results are close to the average, which will indicate that the times taken at the docks are constant and therefore the service provided is consistent. A high standard deviation indicates that the results are spread out over a wide range of values.

The following type of loading docks will mainly be identified.

Figure 1: Saw tooth dock [4]



[2]Adapted from: (Dodge, 2003)
[3]Adapted from: (Davidmlane, 2012)

Figure 2: Inside/outside dock [4]

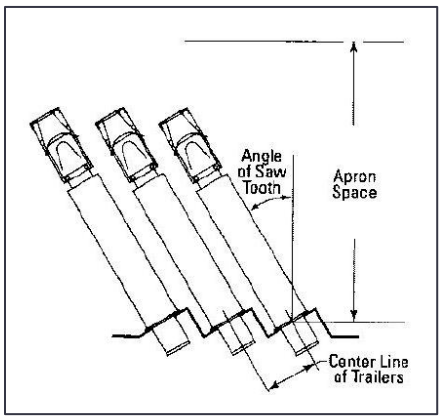
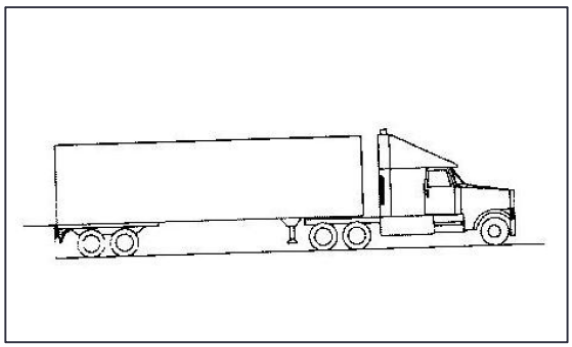


Figure 3: Open docks [4]



2.2. SERVICE TIME DISTRIBUTION

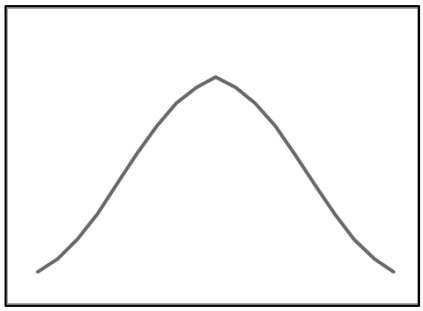
One of the main objectives of the study was to determine the most appropriate service time distributions from observations. Three distributions were investigated for this purpose, namely the Normal, Log Normal and the Exponential distributions. All three these distributions can be calculated with functions that are available in Microsoft Excel.

The Chi-square goodness of fit test (Stat Trek, 2012) was used to select the distribution that provided the best fit to the data.

- Normal distribution (Gaussian distribution)

The Normal distribution (Montgomery & Runger, 2007) has a probability density function that is bell-shaped as seen in Figure 4[4]. The distribution is defined by its mean and standard deviations [5].

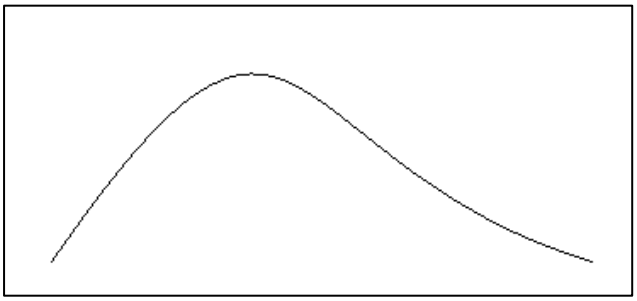
Figure 4: Bell- shaped curve from the Normal distribution



- Log Normal distribution

The Log Normal distribution is almost similar to the Normal distribution, except that the logarithms of the random data are used (Montgomery &Runger, 2007). Alternatively this distribution is able to describe nonnegative random variables (Joubert, 1998). An example of the shape of a Log Normal probability density function is shown in Figure 5[6]:

Figure 5: A graphical example for the Log-Normal distribution

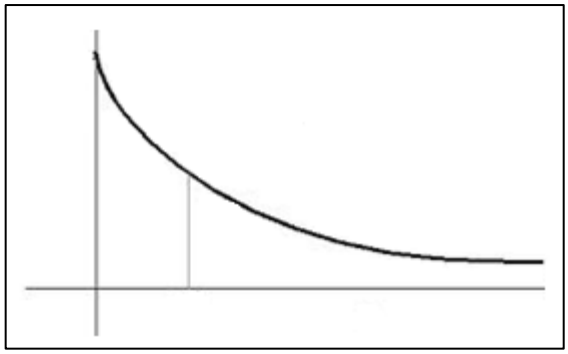


[4] Adapted from: (Flylib, 2012)
[5] Adapted from: (Herbie, 2006). Referenced in Chapter 4.6.
[6] Adapted from: (Ngun, 2012). Referenced in Chapter 4.8.

- Exponential distribution

The exponential distribution is a continuous probability distribution often used in a Poisson process in which events are on-going and independently at a certain rate (Cover et al., 2006:254). The basic shape of the exponential distribution is illustrated in Figure 6[7]:

Figure 6: The equation and basic shape of the exponential distribution [10]



- Chi- Square Goodness of Fit Test

There are four conditions following that should be met before undertaking a chi-square goodness of fit test (Stat Trek, 2012).

1. Firstly, the sampling method should be a simple random sampling.
2. Secondly, the population should be ten or more times larger than the sample.
3. Thirdly, the variable should be categorical.
4. Lastly, the anticipated value of the amount of sample observations in each level should be at least five.

There are four steps in this test (Stat Trek, 2012):

Step 1: State the hypotheses

[7]Adapted from: (Verena, 2012). Referenced [10]

The hypotheses of a chi-square goodness of fit test have the following form:

H_0: The data follow a specified distribution.

H_a: The data do not follow a specified distribution.

Step 2: Formulate an analysis plan

The following elements should be specified:

1. A significance level between 0 and 1.
2. The test method (Step 3).

Step 3: Analyse sample data

Find the following:

1. Degrees of freedom. DF = k-1
2. Expected frequency counts. $E_i = np_i$
3. Test statistics. $X^2 = \Sigma [(O_i - E_i)^2 / E_i]$
4. P-value. The probability of observing a sample statistic as risky as the test statistic. The Chi-Square Distribution Calculator is used to calculate the P-value. Use the DF calculated above.

Where:

DF = Degrees of freedom

k = The number of levels

E_i = Expected frequency counts for i^{th} level

n = Total sample size

p_i = the hypothesized proportion of observations for the i^{th} level

X^2 = A chi-square random variable

O_i = Observed frequency count for the i^{th} level

Step 4: Interpret results

Reject the null hypothesis when the significance level is greater than the P-value.

2.3. ARRIVAL TIME DISTRIBUTION

The inter-arrival time distribution is assumed to follow an Exponential distribution. This distribution is discussed in Section 2.2.

2.4. QUEUING THEORY

Queuing theory is a part of the analysis of the queuing process in order to determine characteristics in the system such as arrival (input) processes, service (output) processes, queue length distributions and waiting times. The waiting times fall under the design of the facility whereas queue length distributions under establishing space requirements. As a starting point, the concepts behind queuing theory should be thoroughly understood and researched to implement it throughout the investigation.
The arrival pattern (a), service facility (b) and queue discipline (c) characteristics are required for the definition of a queuing system. The notation *a*/b/N:(M,c) is used for such definition. The number of service channels is denoted by N and the maximum queue length by M. Infinity is used when M is very large.

The most common queue disciplines (c) would be FIFO (First In First out), LIFO (Last In Last Out) and SIRO (Service In Random Order).FIFO is defined as the first vehicle arriving will be the first to leave. LIFO has the opposite meaning to the FIFO discipline. SIRO is applicable when vehicles arriving and leaving are in random order. Additional disciplines [8] would be reneging, collusion, cycling and jockeying. Reneging is where a vehicle is

[8] Source: (Slideshare, 2012). Referencing 4.17.

in line and leaves before receiving service. Collusion is when vehicles reduce time by collaborating. Cycling is when a vehicle re-joins a queue for a second time just after being served. Jockeying is when a vehicle leaves one queue for another. The common disciplines are patient and do not form a part of the additional disciplines. The service discipline is usually a general discipline (GD), which implements that no specific type of service discipline is considered.

There are different types of queuing systems that can be used. The arrival pattern and service facility can either be an exponential probability density also known as Markov (M), the same value for all items known as deterministic (D), an Erlangian distribution (E_k) or any arbitrary probability distribution (G-General). [9] The queuing systems M/M/1 and M/M/N are respectively a single and a multi-server with random arrival and service times. The system M/M/N(M) is a multi-server where the queue length is limited to a maximum of M vehicles. The queuing system M/M/$\propto$ has an unlimited amount of service channels. G/G/1 is a generalized single server queuing system that is time dependent.

Little's queuing formula is used in queuing systems where a steady-state distribution exists. A steady state distribution occurs when the solution is time independent. The following equations are applicable to analytical queuing models (Winston, 2004):

$L = \lambda W$

$L_q = \lambda W_q$

$L_s = \lambda W_s$

Where:

λ = mean arrival rate

μ = mean service rate

L = average number of vehicles present in the queuing system

[9] Adapted from: (EventHelix, 2011). Referencing 4.16.

L_q = average number of vehicles waiting in line

L_s = average number of vehicles in service

W = average time a delivery vehicle spends in the system

W_q = average time a vehicle spends in line

W_s = average time a vehicle spends in service

ρ = traffic intensity in queuing systems: $\rho = \lambda / \mu$

Alternately when a queue is finite λ is replaced with λe. Subsequently there are the M/M/s queuing system examples with equations[10]:

- M/M/s/GD/∞/∞ models

  This is a multi- server, Poisson/ Exponential model. It is very similar to the M/M/1/GD/∞/∞ model except that the amount of service channels is more than one.

  $W_q = \{[[(\rho^{(c+1)})/c!c]*[1/(1-\rho/c)^2]]*2\}/\lambda$

- The M/G/s queuing system has an Exponential inter arrival time and the service distribution is Log Normal. This would be a good candidate to use in the future when the solutions for this system are available and stable. For the purpose of this project an M/M/s queuing model will be simulated and further simulation will be done to be suitable for the type of distributions found.

2.5. SIMULATION

Simulation is the process of designing a model from a theoretical or an actual physical system, executing it in a program and analysing the outputs to predict the behaviour of the system

[10] Source: (Winston, 2004). Referencing 4.14

(Fishwick, 1995). This prediction of how the system will respond to the surroundings may help identify changes that will improve the system. Visual basics will be used to write the model.

Random number generator

Random number generators are basic tools in modelling. A bad generator may ruin a simulation and thus it is deemed important to use a good random number generator in the simulation model (Hellekalek, 1998). The built in random number generator of Microsoft Excel will not work sufficiently for the purpose of the simulation model. There are a few known generators that may be used, namely the Marsaglia polar method and Mersenne twister. For the purpose of this study, the Mersenne twister was used.

Mersenne Twister (Matsomoto & Nishimura, 1998)

The Mersenne twister is an algorithm used to generate pseudorandom numbers based on a linear recurrence of a matrix over a finite binary field ($\mathbb{F}_2$). It provides a long period of 2^{19937} – 1 with a 32- bit word length, which guarantees better quality in the generator. The working area only uses 624 words.

The algorithm generates word vectors sequentially, which are uniform pseudorandom integers in the range [0, 2^w – 1]. The vectors are real numbers between 0 and 1.

The linear recurrence on which Mersenne twister is based:

$$\bar{x}_{k+n} \coloneqq \bar{x}_{k+m} \oplus (\bar{x}_k^u | \bar{x}_{k+1}^l)A, (k = 0,1, \dots) \qquad (2)$$

Where:

n = the degree of the recurrence

r = (hidden in $\bar{x}_k^u$), $0 \leq r \leq w-1$

m = middle word, $0 \leq m \leq n$

A = a constant w x w matrix with entries in $\mathbb{F}_2$

w = word size

u, l = tempering bit shifts

$\bar{x}_k^u$ = upper w – r bits of $\bar{x}_k$

$\bar{x}_{k+1}^l$= lower r bits of $\bar{x}_{k+1}$

$\bar{a}$ = rational normal form of twist matrix coefficients

The $(\bar{x}_k^u | \bar{x}_{k+1}^l)$ is a word vector obtained by concatenating $\bar{x}_k^u$ and $\bar{x}_{k+1}^l$, then the matrix A is multiplied with this vector. Consequently add $\bar{x}_{k+m}$ and generate the next vector $(\bar{x}_{k+n})$.

The form of matrix A:

$$A = \begin{pmatrix} 0 & I_{w-1} \\ a_{w-1} & (a_{w-2}, \dots, a_0) \end{pmatrix} \quad (3)$$

With I_{n-1} as the (n – 1) x (n – 1) identity matrix.

Bit operations can be used to calculate $\bar{x}$A:

$$\bar{x}A = \begin{cases} \bar{x} \gg 1 & \text{if } x_0 = 0 \\ (\bar{x} \gg 1) \oplus \bar{a} & \text{if } x_0 = 1 \end{cases} \quad (4)$$

Where $\bar{a} = (a_{w-1}, a_{w-2}, \dots, a_0)$ and $\bar{x} = (x_{w-1}, x_{w-2}, \dots, x_0)$. A T matrix (w x w) is multiplied from the right with each generated word. For this tempering matrix, the following transformations are used:

$$\bar{y} := \bar{x} \oplus (\bar{x} \gg u) \qquad \bar{y} := \bar{y} \oplus ((\bar{y} \ll s) AND\ \bar{b})$$
$$\bar{y} := \bar{y} \oplus ((\bar{y} \ll t) AND\ \bar{c}) \qquad \bar{z} := \bar{y} \oplus (\bar{y} \gg l) \quad (5)$$

Where $\bar{b}$ and $\bar{c}$ are bitmasks for the word size and l, s, t and u are integers.

Implementing (4) in seven steps, let $\bar{x}[0{:}n-1]$ be an array (n = unsigned integers of word size, i = integer variable, $\bar{u}\&\overline{ll}\&\bar{a}$ be unsigned constant integers of word size).

Step 1: $\bar{u} \leftarrow \underbrace{1 \dots 1}_{w-r}\underbrace{0 \dots 0}_{r}$; $(bitmask\ for\ upper\ w-r\ bits)$

$\overline{ll} \leftarrow \underbrace{1 \dots 1}_{w-r}\underbrace{0 \dots 0}_{r}$; $(bitmask\ for\ lower\ r\ bits)$

$\bar{u} \leftarrow a_{w-1}a_{w-2} \dots a_1a_0$; $(the\ last\ row\ of\ the\ matrix\ A)$

Step 2: $i \leftarrow 0$

$\bar{x}[0], \bar{x}[1], \dots, \bar{x}[n-1] \leftarrow (nonzero\ initial\ values)$

Step 3: $\bar{y} \leftarrow (\bar{x}[i]AND\ \bar{u})\ OR\ (\bar{x}[(i+1)mod\ n])\ AND\ \overline{ll})$;

$(computing\ (\bar{x}_i^u | \bar{x}_{i+1}^l))$

Step 4: $\bar{x}[i] \leftarrow \bar{x}[(i+1)mod\ n] \oplus (y \gg 1)$

$$\bigoplus \begin{cases} 0 & if\ the\ least\ significant\ bit\ of\ \bar{y} = 0; (\times A) \\ \bar{a} & if\ the\ least\ significant\ bit\ of\ \bar{y} = 1; (\times A) \end{cases}$$

Step 5: $\bar{x}[i]T =$

$\bar{y} \leftarrow \bar{x}[i]$

$\bar{y} \leftarrow \bar{y} \oplus (\bar{y} \gg u)$; $(shiftright\ \bar{y}\ by\ u\ \&\ add\ to\ \bar{y})$

$\bar{y} \leftarrow \bar{y} \oplus ((\bar{y} \ll s)\ AND\ \bar{b})$

$\bar{y} \leftarrow \bar{y} \oplus ((\bar{y} \ll t)\ AND\ \bar{c})$

$\bar{y} \leftarrow \bar{y} \oplus (\bar{y} \gg l)$

Output $\bar{y}$

Step 6: $i \leftarrow (i+1)mod\ n$

Step 7: Go to step 2

Period parameters are w, n, m, r and $\bar{a}$ (Matrix A) that determine the period. Tempering parameters for k- distributions to v-bit accuracy are integer parameters (l, u, s, t) and vector parameters $(\bar{b}, \bar{c})$.

Marsaglia Polar Method (Marsaglia&Bray, 1964)

This is a pseudorandom number sampling for giving independent normal random variables. The random variables are uniform over [0, 1]. It choses random points [X, Y] as follows:

$$\boldsymbol{X = v_1\sqrt{\frac{-2ln(v_1^2+v_2^2)}{(v_1^2+v_2^2)}}} \qquad \boldsymbol{Y = v_2\sqrt{\frac{-2ln(v_1^2+v_2^2)}{(v_1^2+v_2^2)}}}$$

Where v is uniform between -1 and 1, conditioned by $\boldsymbol{v_1^2 + v_2^2 < 1}$.

2.6.CHAPTER SUMMARY

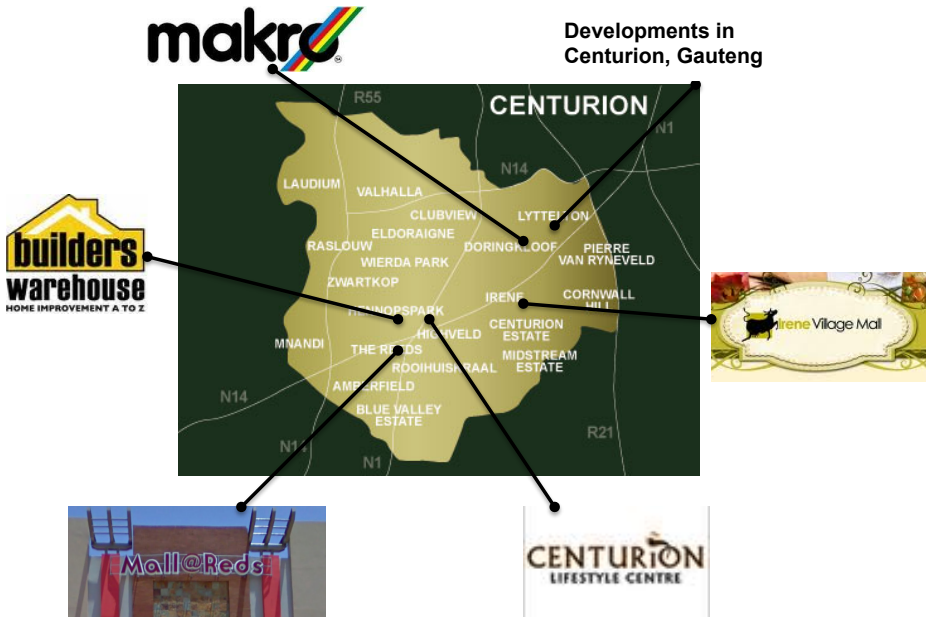
The literature study is a basis for the ideologies that will follow. The question lists and time studies will be done on the following developments in Centurion: Makro, Builder's Warehouse, Mall @ Reds, Irene Mall and Lifestyle Centre. The time studies have to be done with the calculated sample size in chapter 3 to ensure accurate data. The data from the time studies will be presented graphically on two graphs for each site with the cumulative percentage aligned with the loading or parking times. Moreover the simulation model will be done in Visual Basics and the Mersenne Twister will be used as the random number generator. Supplementary literature will be utilized as the project develops.

Chapter 3. DATA COLLECTION

Observations were undertaken at four developments in order to obtain data on service time distributions at loading docks as seen in Appendix B. The following five sites in Centurion were selected for this purpose (shown in Figure 7):

1) Makro
2) Builder's Warehouse
3) Mall @Reds
4) Irene Mall
5) Lifestyle Centre

Figure 7: Developments in Centurion



3.1. SITE DEVELOPMENT PLANS AND GOOGLE MAP PICTURES

Site development plans were obtained for each of the developments in order to obtain information on the number of delivery docks and parking areas. Use was also made of Google Map (provided in Appendix B) to obtain this information. The

number of loading docks and parking areas are summarised in Table 2.

3.2. SAMPLE SIZE REQUIREMENTS

The required sample sizes for the service time observations were determined by using the t-distribution in Microsoft Excel. The lower and upper bound of the confidence interval were calculated with equation (1).

The sample mean (average service time per vehicle) is obtained by using table B.2 and it is taken as 30 min/vehicle. The sample standard deviation (S) is also taken as 30 min/vehicle. The t- distribution is calculated with a desired confidence level of 99% by using the Microsoft Excel formula: =_xlfn.T.INV.2T(0.05,n-1). The confidence interval is shown in Figure 8 as a function of the sample size.

Figure 8: Lower bound/Mean/Upper bound (Y-axis) versus Sample size of vehicles (X-axis)

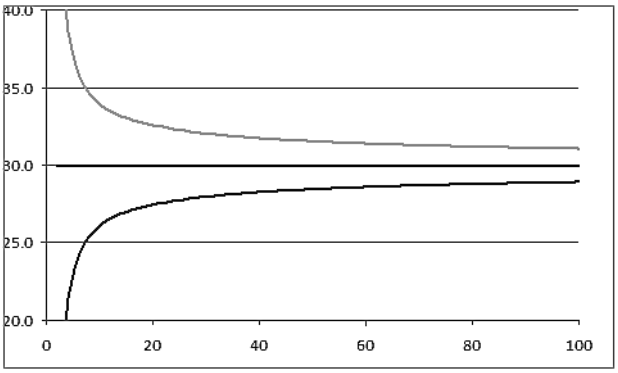


Figure 8 shows that the confidence interval reduces exponentially with increasing sample size smaller than 20 to 30. For larger sample sizes, increasingly larger sample samples are required to significantly reduce the confidence intervals.

The cost of the observations is relatively high and with the limited resources available for the purposes of the study, the decision was used to limit the sample size to a minimum of 30.

3.3. TIME STUDIES

The design of the time study is in Appendix A. Time studies were undertaken at each site. Observations were made of the following times:

a) The times the delivery vehicles entered and left the parking areas
b) The times when vehicles started and ended to load.

In some cases, loading also occurred in the parking area, in these cases, the activity was recorded as a service time.

Both the parking and loading times were timed by using watches. The registration number, the type of vehicle and the product being delivered were also recorded.

It was also noted during the studies that offloading does not start immediately and that goods are first counted and inspected by an inspector before offloading commencement. In some cases, the time for such counting and inspection actually took longer than the actual time that was required for offloading the vehicles. The inspection time was included in the service time.

The completed time studies at each of the five sites are provided in Appendix C.

3.4. QUESTIONAIRE

An example of the Questionnaire is provided in Appendix A. The completed Questionnaires are in Appendix C. The Questionnaires were used to establish whether the sites are big enough, to ascertain what kind of loading docks are present, the applicability of queues and the design of the loading area. It gives additional information on the loading docks. A summary of the questionnaires results follows in table 2.

Table 2: Question lists summary

Questions summarized	Site 1	Site 2	Site 3	Site 4	Site 5
Enough space on site?	Yes	No, because stock is taking up space.	Yes	Yes	Yes
Minimal interaction with other traffic?	No	Yes	Yes	Yes	Yes
Queue outside?	-	Yes	Only at one big store.	Yes	At most two at a time.
Amount of vehicles outside?	-	Approximately five.	-	An average of four.	At most two.
Loading docks design?	Rear	Rear/ saw tooth	Rear	Rear	Rear
Amount of loading docks?	5	6	6	8 in total	4 in total
Amount of parking areas?	-	-	-	-	-

Additional data:	There are vehicles delivering from the parking area. People tend to take their time.	Very long queue. Some deliverymen sleep while waiting.	There are shops with private loading docks.	Large loading zone, but stock tends to take up some space.	This loading zone seems to operate well.

3.5. CHAPTER SUMMARY

The sample size at each site should be more than 30 observations as stated in the chapter. The results of the time studies and question list will be used for further data analysis and discussion of results.

Chapter 4. DATA ANALYSIS

The type of distribution that best suits the recorded data should be identified.

4.1. OVERVIEW OF THE DATA

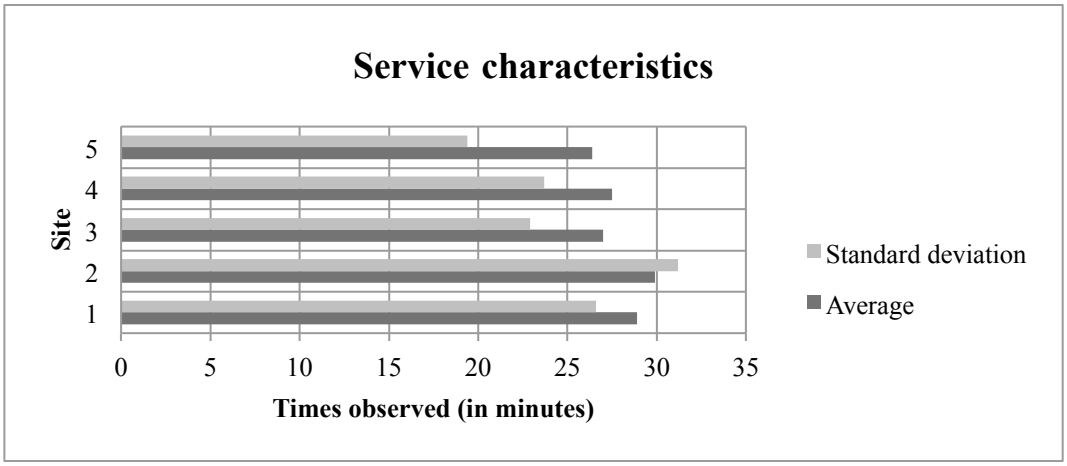
The statistical characteristics for the observed parking and service times at the different sites are summarized in Table 3.The observed data are provided in Appendix C.

The characteristics in Table 3 provide an indication of how the parking and service characteristics differ at each site. The differences between the service times for the sites are graphically shown in Figure 9.

Table 3: Statistical measures for the service times at the different sites

	Parking time		Service time	
Site	Std.Dev.	Average	Std.Dev.	Average
Site 1	13.5	4.7	26.6	28.9
Site 2	51.8	27.3	31.2	29.9
Site 3	10.0	4.7	22.9	27.0
Site 4	6.1	1.9	23.7	27.5
Site 5	15.9	4.24	19.4	26.4

Figure 9: Service time averages and standard deviations at the various sites



At site 2 (Builder's Warehouse in Centurion), the average and standard deviations of both the parking and service times are the highest. The parking times are significantly higher than at the other sites indicating that the number of loading docks may be inadequate. The service times are also higher, but not by much compared to the other sites.

Observations were also undertaken of "move-up" times. These are the times that are required for a vehicle to move from the parking area to the loading area. A summary for the move-up times at the five sites is given below.

Table 4: Average move-up times (in minutes) of the five sites

Site	Average move- up time (in minutes)
1	2
2	2.27
3	Not applicable
4	Not applicable
5	1.33
Median	2

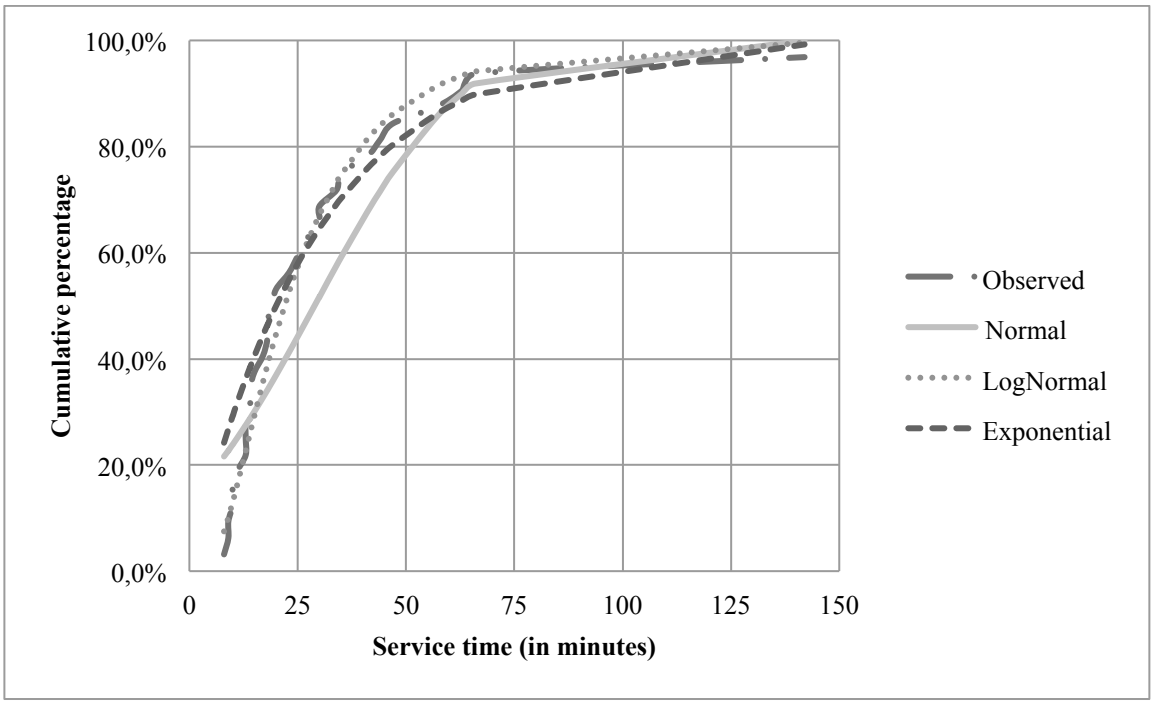
The move-up times for site 3 and 4 are not applicable, because the delivery vehicles either started loading in parking directly or they directly started loading.

4.2. BEST FITTED DISTRIBUTION

4.2.1. Best fitted distribution for site 1

The observations on site 1 were collected at Irene Mall, in Centurion, on a Friday, between 08:00 and 12:00. The recorded data are provided in Appendix C. The observed distributions with the fitted distributions are shown in Figure 10.

Figure 10: The Normal, Log Normal and Exponential service time distributions fitted to the data for site 1



In Figure 10 it can be seen that the Log Normal distribution reflects the observed probabilities the best. The chi- square goodness of fit test will be done in order to ensure that the Log Normal distribution is the best fit.

Chi – square Goodness of Fit test for site 1

The hypotheses were stated (seen on next page):

H_0 = The data are consistent with a Log Normal distribution

H_a = The data are not consistent with a Log Normal distribution

Groups were formed in order to have frequencies more than five as shown in Appendix D. Five groups of observed were formed. The degrees of freedom are calculated to be four as shown in Appendix D. The level of significance is taken as 99%.

The value for the Chi- square test for site 1 is 1.21 and the P- value equals 0.12. It concludes that H_0 is not rejected.

4.2.2. Best fitted distribution for site 2

The observations on site 2 were collected at Builder's Warehouse, in Centurion, on a Thursday, between 10:00 and 14:20. The recorded data are provided in Appendix C. The distributions are shown in Figure 11.

Figure 11: The Normal, Log Normal and Exponential service time distributions fitted to the data for site 2

In Figure 11 it can be seen that the Log Normal distribution reflects the observed probabilities the best. The chi- square goodness of fit test will be done in order to ensure that the Log Normal distribution is the best fit.

Chi – square Goodness of Fit test for site 2

The hypotheses were stated:

H_0 = The data are consistent with a Log Normal distribution

H_a = The data are not consistent with a Log Normal distribution

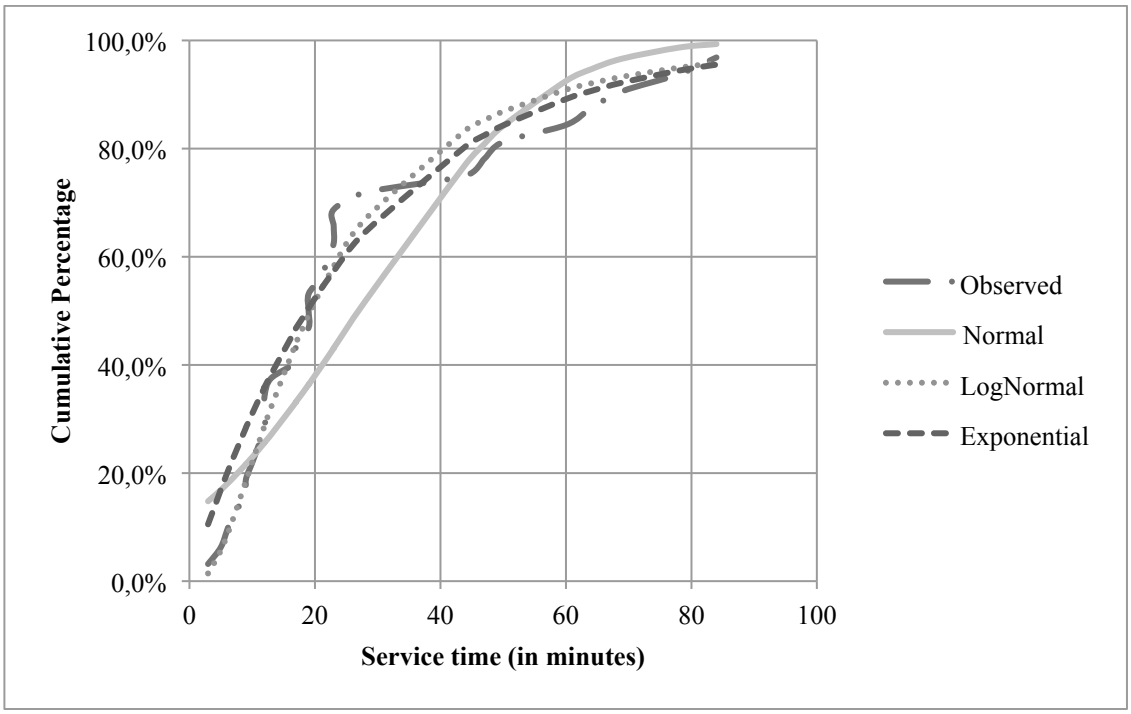
Groups were formed in order to have frequencies more than five as seen in Appendix D. There are five groups formed. The degrees of freedom are calculated to be four as seen in Appendix D. The level of significance is taken as 99% Confident.

The value for the Chi- square test for site 2 is 2.09 and the P- value equals 0.28. It concludes that H_0 is not rejected.

4.2.3. Best fitted distribution for site 3

The observations on site 3 were collected at Lifestyle Centre, in Centurion, on a Wednesday, between 07:40 and 10:30. The recorded data are provided in Appendix C. The distributions are shown in Figure 12.

Figure 12: The Normal, Log Normal and Exponential service time distributions fitted to the data for site 3



In Figure 12 it can be seen that the Log Normal distribution reflects the observed probabilities the best. The chi- square goodness of fit test will be done in order to ensure that the Log Normal distribution is the best fit.

Chi – square Goodness of Fit test for site 3

The hypotheses were stated:

H_0 = The data are consistent with a Log Normal distribution

H_a = The data are not consistent with a Log Normal distribution

Groups were formed in order to have frequencies more than five as seen in Appendix D. There are five groups formed. The

degrees of freedom are calculated to be four as seen in Appendix D. The level of significance is taken as 99% Confident.

The value for the Chi- square test for site 3 is 4.38 and the P- value equals 0.65. It concludes that H_0 is not rejected.

4.2.4. Best fitted distribution for site 4

The observations on site 4 were collected at Makro, in Centurion, on a Tuesday, between 08:52 and 12:40. The recorded data are provided in Appendix C. The distributions are shown in Figure 13.

Figure 13: The Normal, Log Normal and Exponential service time distributions fitted to the data for site 4

In Figure 13 it can be seen that the Exponential distribution reflects the observed probabilities the best and it is confirmed by the Chi-square Goodness of Fit test.

Chi – square Goodness of Fit test for site 4

The hypotheses were stated (seen on next page):

H_0 = The data are consistent with an Exponential distribution

H_a = The data are not consistent with an Exponential distribution

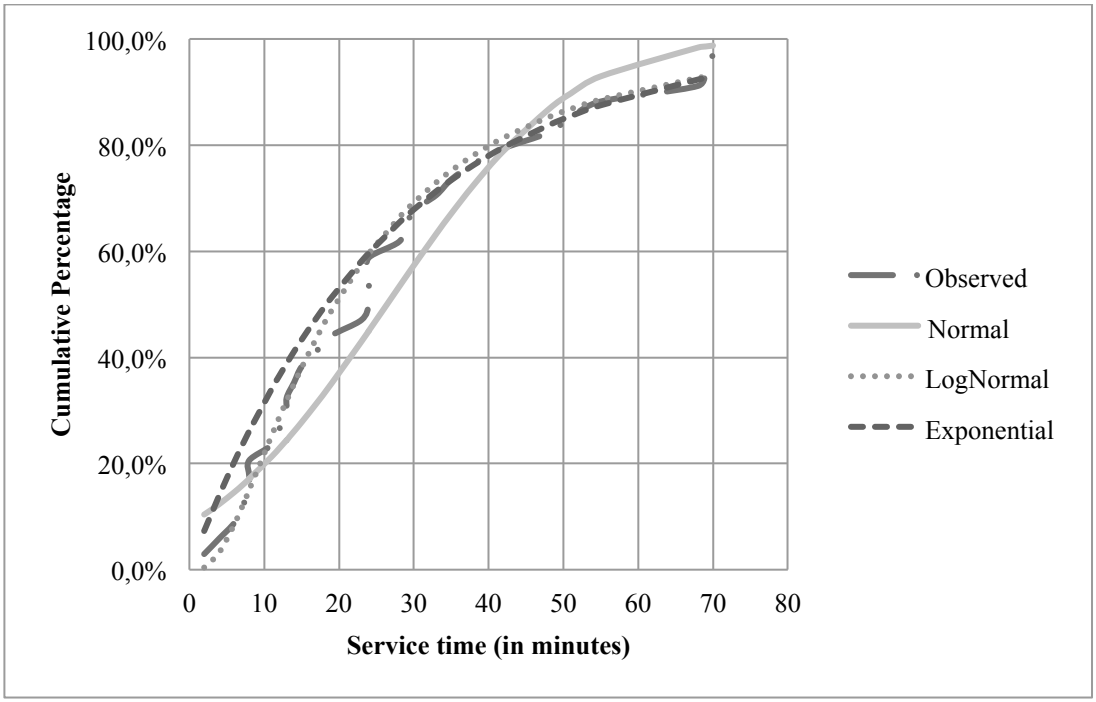
Groups were formed in order to have frequencies more than five as seen in Appendix D. There are five groups formed. The degrees of freedom are calculated to be four as seen in Appendix D. The level of significance is taken as 99% Confident.

The value for the Chi- square test for site 4 is 1 and the P-value equals 0.09. It concludes that H_0 is not rejected.

4.2.5. Best fitted distribution for site 5

The observations on site 5 were collected at Mall@Reds, in Centurion, on a Monday, between 08:25 and 11:33. The recorded data are provided in Appendix C. The distributions are shown in Figure 14.

Figure 14: The Normal, Log Normal and Exponential service time distributions fitted to the data for site 5



In Figure 14 it can be seen that the Exponential distribution reflects the observed probabilities the best and it is confirmed by the Chi-square Goodness of Fit test.

Chi – square Goodness of Fit test for site 5

The hypotheses were stated:

H_0 = The data are consistent with a Exponential distribution

H_a = The data are not consistent with a Exponential distribution

Groups were formed in order to have frequencies more than five as seen in Appendix D. There are five groups formed. The degrees of freedom are calculated to be four as seen in Appendix D. The level of significance is taken as 99% Confident.

The value for the Chi- square test for site 5 is 0.82 and the P- value equals 0.06. It concludes that H_0 is not rejected.

4.3. CHAPTER SUMMARY

The service time distributions will be taken into account throughout the project, but not the parking times. For the use of the simulation model move-up times will be taken as 120 seconds. The best fitted distribution for the data overall is the Log Normal distribution as established in the chapter.

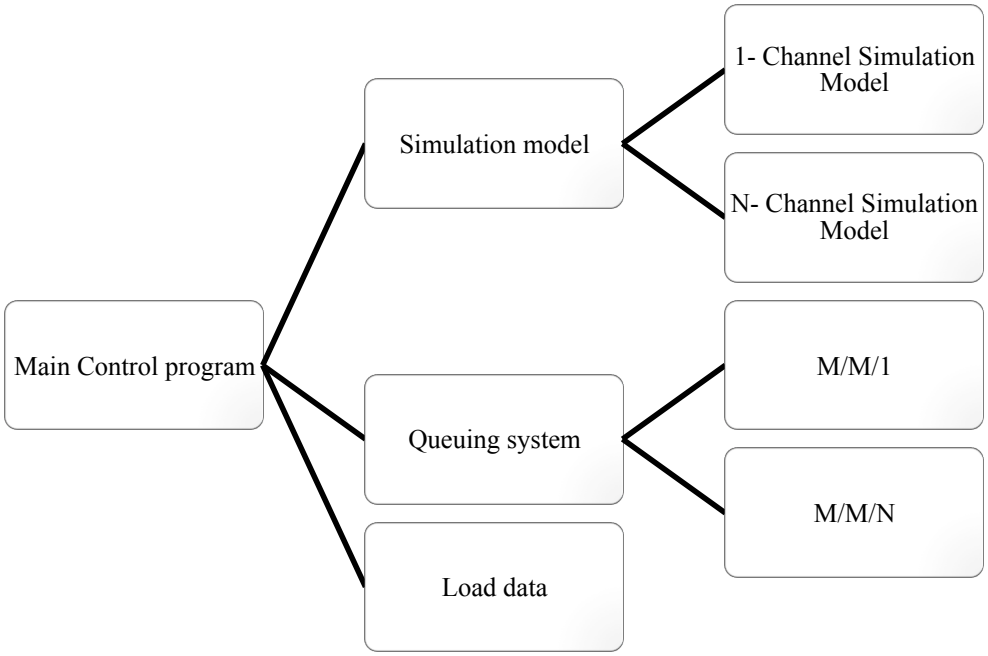
The P-value calculated in the Chi-square Goodness of Fit test of the Log Normal distribution is the lowest of the three distributions at three of the five sites as seen in Appendix D, therefore it is a further confirmation that the Log Normal distribution is the best fit overall. It is important to note that the distribution of different delivery docks should be identified before considering which model to use.

Chapter 5. SIMULATION MODEL AND QUEUING THEORY

5.1. INTRODUCTION

The simulation model and the queuing system were coded in Visual Basics Excel with the assistance from Dr. S.C van As. The two methods were being compared with the purpose of verifying the accuracy of the simulation model.

Figure 15: The flow of the coding in Visual Basics



The software code for the program is provided in Appendix E. The code for the random number generator is provided in Appendix E.1.

The Main Control Program controls the different programs namely Simulation model, Queuing system and Load data. In the main control program the general variables are publicly defined. The code for the main program is provided in Appendix E.2.

In the load data program the following functions are undertaken: Load data, load parameters and termination. This program has the duty to load all the necessary data. The coding of the load data program is provided in Appendix E.3.

5.2. SIMULATION MODEL

The simulation model forms a very important part of the whole model. Provision is made for a 1-Channel Simulation model and an N-Channel Simulation model. The main purpose of the software is to determine percentile queue lengths.

The simulation software provides for an arrival time generator, a service time generator as well as a move-up time generator. The coding for the simulation model is provided in Appendix E.4.

The simulation terminates when 5,000,000 vehicles have been simulated.

The inputs for the simulation model are as follows:

- Number of channels
- Arrival time distribution
    - E = Poisson
    - N = Normal
    - L = Log Normal
- Service time distribution
    - E = Poisson
    - N = Normal
    - L = Log Normal
- Average inter-arrival time (seconds)
- Standard deviation of Arrival times (not used for exponential distribution)
- Average move-up times (seconds)

- Standard deviation of move-up times (not used for exponential distribution)

The outputs for the simulation model are:

- Traffic ratio (%)
- The average delay
- The average queue
- The 90^{th}, 95^{th} and 99^{th} percentile for the queue length

5.3. QUEUING SYSTEM

The queuing system software provides for the M/M/1 as well as the M/M/N (or M/M/s) queuing systems. The queuing system is based on the previously mentioned queuing model and thus only applicable when arrival and service times are exponentially distributed. The coding for the queuing system can be seen in Appendix E.5.

The inputs for the queuing models are:

- Number of channels
- Average inter-arrival time (seconds)
- Average move-up times (seconds)

The outputs for the queuing theory will be:

- Traffic ratio (%)
- The average delay
- The average queue
- The 90^{th}, 95^{th} and 99^{th} percentile for the queue length

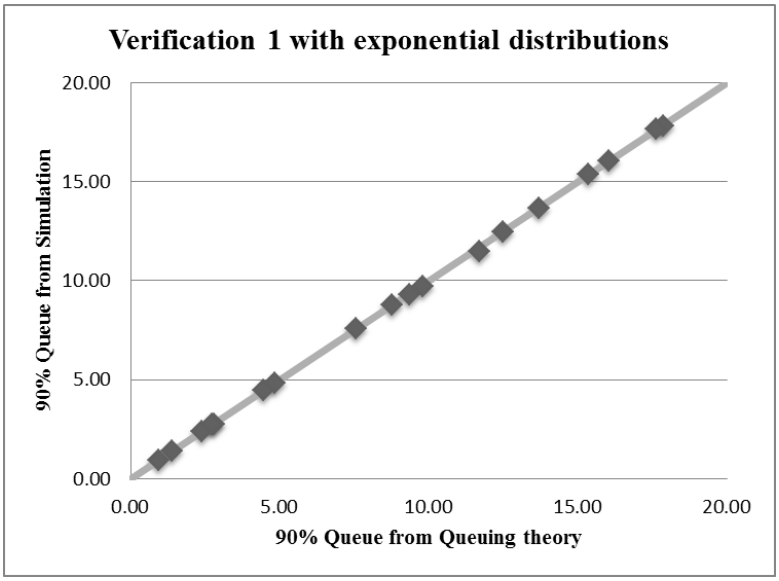
5.3. VERIFICATION OF SIMULATION MODEL

5.3.1. Verification of simulation model with exponential distributions

The simulation model was verified by comparing the results of the model with those calculated by means of the queuing system. For this purpose, the arrival and service times were assumed to follow the Exponential distribution. The move-up times were taken as zero.

In order to verify the correctness of the Simulation, a graph is drawn with the 90% Queue lengths determined by means of the Simulation against the 90% Queue lengths obtained by means of the Queuing theory. The comparison is shown in Figure 16 which indicates that the results fall on a 45 degree line, which is an indication that that the Simulation is working correctly.

Figure 16: Verification of simulation model with exponential distributions

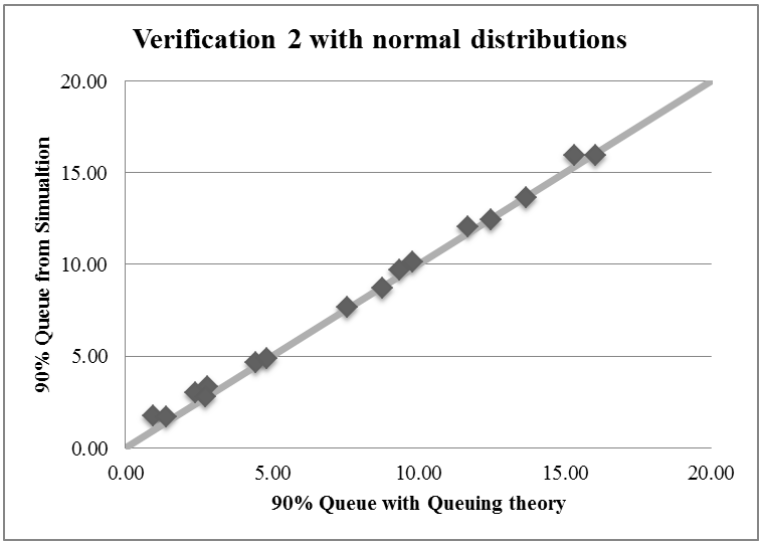


5.3.2. Verification of simulation model with normal distributions

A comparison was also undertaken using the Normal and Log Normal distributions in the simulation models. The results of the comparisons are shown in Figures 17 and 18. Both graphs show

that the queue lengths fall approximately on the 45-degree line. There are some differences but these differences are not very large. It therefore appears that the simulation model is also correct when the Normal and Log Normal distributions are used.

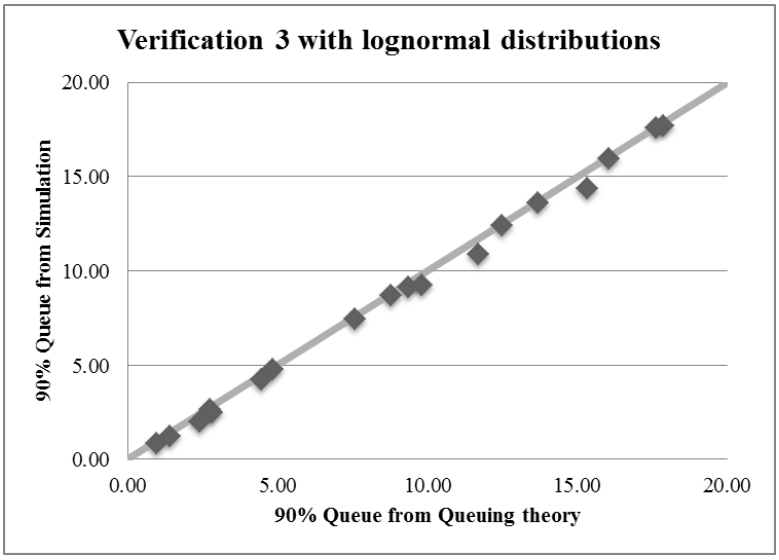
Figure 17: Verification of simulation model with normal distributions



5.3.3. Verification of simulation model with Log Normal distributions

The third verification is to test whether the Simulation is working correctly when the Arrival and Service Distributions are Log Normal as seen in Table 34. The move-up time is taken as zero. In order to verify the precision of the Simulation, a graph is drawn with the 90% Queue results of the Simulation against the 90% Queue results of Queuing theory. In this verification it can be seen in Figure 18 that the graph lays approximately on a 45degree line, which depicts that the Simulation is working correctly.

Figure 18: Verification of simulation model with Log Normal distributions



5.4. CHAPTER SUMMARY

The verifications of the simulation model state that it is working correctly. Ultimately the simulation model will give realistic outputs according to a loading system with an exponential inter-arrival time distribution and a Log Normal service time distribution. It provides realistic results for loading docks that the M/M/s queuing model cannot offer. It concludes that the Simulation model may be used for the evaluation of loading docks, because it gives accurate results.

Chapter 6. OUTCOME OF RESEARCH

The Simulation model was used to develop new traffic ratio standards as seen in table 5. The existing approaches overestimate the required number of loading docks and parking spaces at developments as seen when comparing the new ratios in table 5 with the old ratios in table 8 when the service times are Log Normally distributed. The new ratios could determine the required number of loading docks more accurately for Log Normal service times. The Simulation model could be used to develop other loading dock standards as well.

Table 5: New calculated ratios (%) from the simulation model

No. of loading docks	New traffic ratio (Percentage) for different Number of Parking spaces						
	0	1	2	3	4	5	6
1	30	40	50	60	65	70	80
2	60	80	100	120	130	140	160
3	90	120	150	180	195	210	241
4	120	160	200	240	261	280	320
5	150	200	250	300	325	350	400
6	180	240	299	360	389	420	480
7	210	280	351	421	456	490	560
8	239	320	401	481	521	560	641
9	271	361	451	541	587	631	721
10	300	400	501	601	652	702	801
11	329	440	551	661	717	771	877
12	259	481	601	719	781	843	963
13	391	520	651	779	845	911	1040
14	420	560	701	841	910	981	1122
15	449	600	751	901	976	1053	1205
16	484	641	802	960	1042	1119	1280
17	510	680	850	1021	1107	1189	1360
18	547	719	900	1079	1172	1259	1439
19	533	761	951	1144	1234	1329	1521
20	603	800	1001	1202	1300	1398	1600

Chapter 6. CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

The comparison between the simulation model and queuing system concluded that the simulation model could be used for loading docks and parking spaces of delivery goods at developments, with an Exponential arrival time distribution and a Log Normal service time distribution. The current models that are based on the M/M/s queuing system could be used with the assumption that the arrival and service times are Exponential distribution. The majority of the delivery docks follow a Log Normal distribution and thus it is recommended that the new improved model should rather be used to estimate standards for the number of loading docks and parking spaces at developments.

6.2. RECOMMENDATIONS

In order for the simulation model to provide realistic results, it is recommended that loading docks should operate with as little as possible delays. Delays could occur, because of stock taking up space at loading docks, thus this should be avoided. In the future vehicle trip generation rates and the geometric design of loading docks and parking spaces could also be considered in the project to go into further detail of the design of loading docks and parking spaces.

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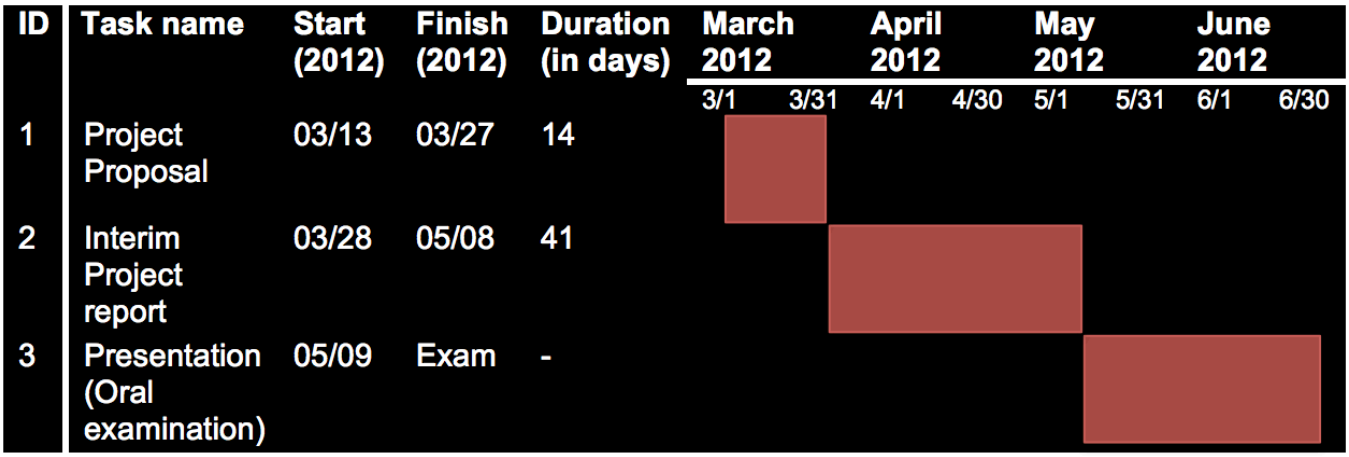
Appendix A

Figure 19: Gantt chart for BPJ 410 and BPJ 420



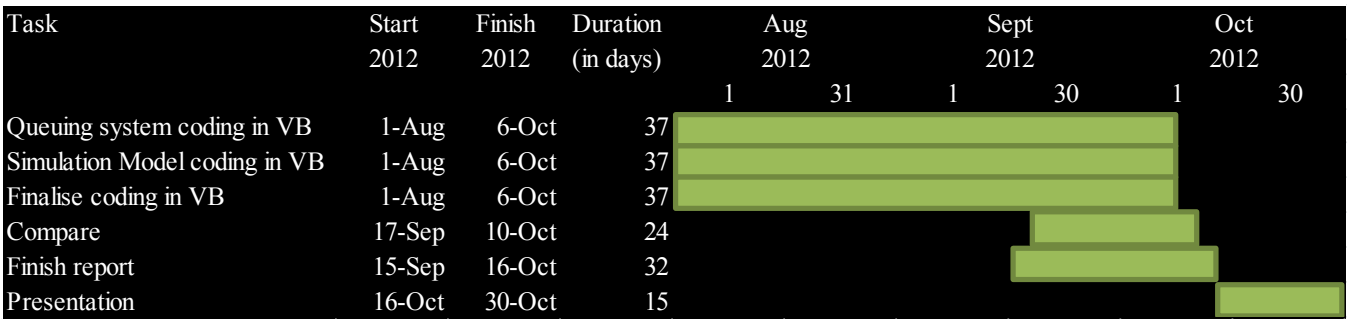


Table 6: Basic observations table for use of time studies

Basic observations of delivery systems											
Place:											
Weekday:											
Observers:											
	Parking		Loading in Parking		Loading		Total	Total	Reg.		
Vehicle	In	Out	Start	End	Start	End	parking time	loading time	No.	Type	Product
1											

Table 7: Delivery vehicle trip generation rates and service times

Land-use	Peak hour trip generation rate/100m^2	Inbound Split	Average service time per vehicle (min/veh)
Offices	0.04	0.50	27
Retail	28 GLA^(-0.537)	0.50	20
Hyperamas	28 GLA^(-0.537)	0.50	33
Industrial	0.004	0.50	38

Table 8: Standard number of loading docks and parking spaces

No. of loading docks	Traffic ratio (Percentage) for different Number of Parking spaces						
	0	1	2	3	4	5	6
1	32	46	56	63	68	72	75
2	83	105	121	132	141	147	153
3	142	170	189	204	215	225	232
4	207	238	261	278	292	303	312
5	276	309	335	354	371	383	394
6	347	383	410	432	449	464	476
7	421	458	487	511	530	545	559
8	495	534	566	590	611	628	642
9	572	612	644	671	693	711	726
10	650	691	725	752	775	794	810
11	728	771	805	834	858	878	895
12	808	851	887	917	941	962	980
13	888	932	968	1000	1026	1047	1066
14	969	1014	1051	1084	1110	1133	1152
15	1052	1097	1134	1167	1194	1218	1238
16	1133	1179	1218	1251	1280	1304	1325
17	1215	1263	1302	1336	1365	1389	1411
18	1300	1346	1386	1420	1451	1476	1498
19	1383	1431	1471	1507	1537	1562	1585
20	1468	1516	1556	1592	1622	1650	1672

Adapted from the *South African Traffic Impact and Site Traffic Assessment Standards and Requirements Manual*(7.27)

Figure 20: Question list template

Question list for delivery services

Place: _____
Weekday: _____
Observer: _____

1. Are the vehicles able to turn on site and avoid reversing onto or from public roads?

_____

2. Is there minimal interaction between service vehicles and other traffic?

_____

3. Is there a queue outside as well?

_____

4. How many vehicles are outside that cannot be accommodated?

_____

5. Loading dock design:

Rear	Side	Other (explain 6)

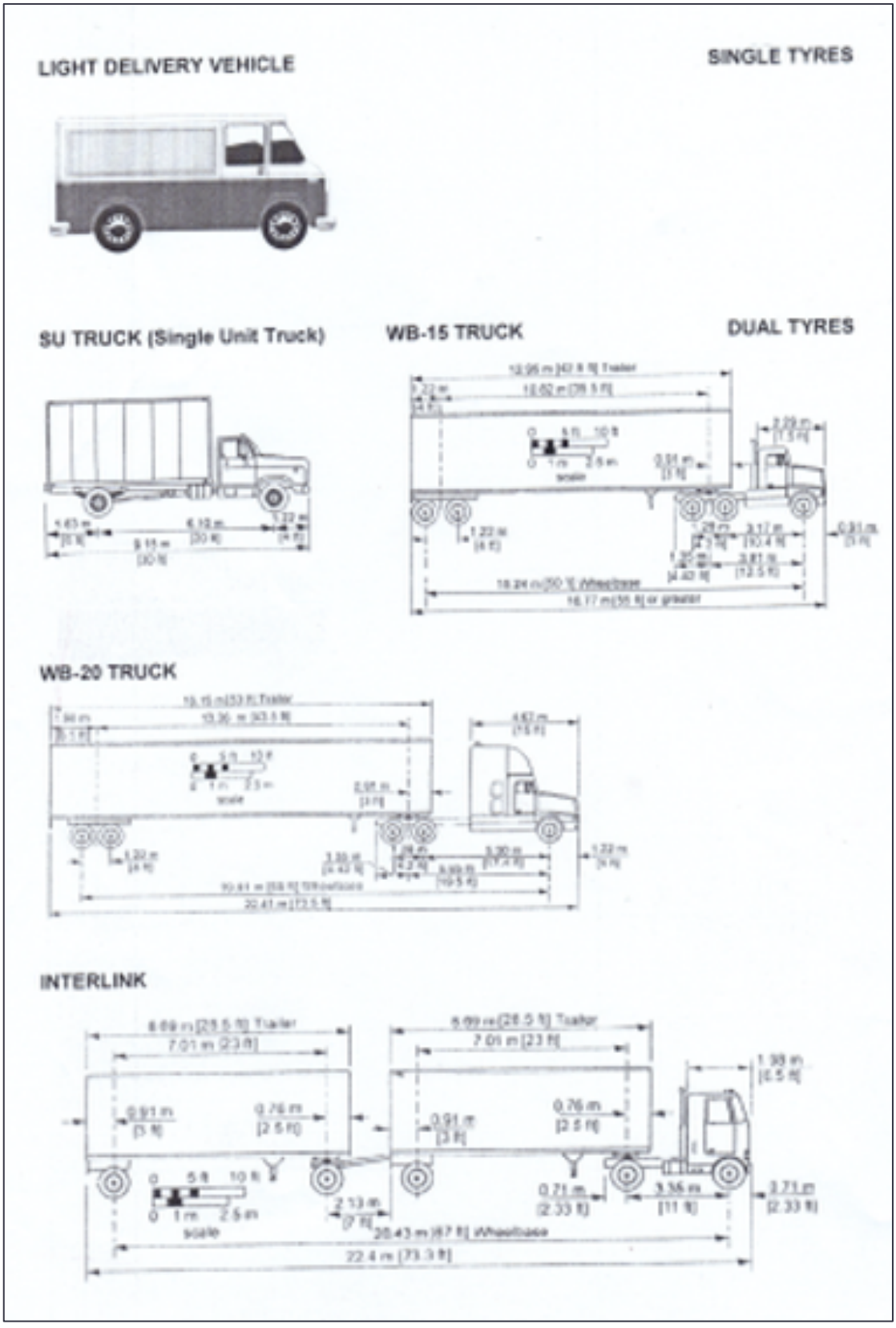
- How many loading docks? _____
- How many parking areas? _____
- Description of loading docks (ex. Saw tooth docks, 90 degrees etc.)

_____

6. Additional data:

_____
_____
_____
_____
_____
_____
_____

Figure 21: Typical size classifications for delivery vehicles



Appendix B

The site development plans and pictures from Google Maps site 1 to 5 (Site 1- Irene Mall, Site 2- Builder's Warehouse, Site 3- Lifestyle Centre, Site 4- Makro and Site 5- Mall @ Reds)

Figure 22: Site1

Figure 23: Site2

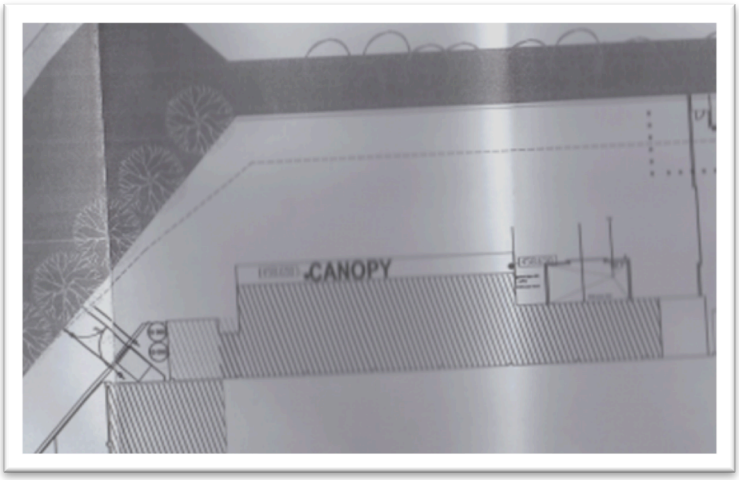


Figure 24: Site3

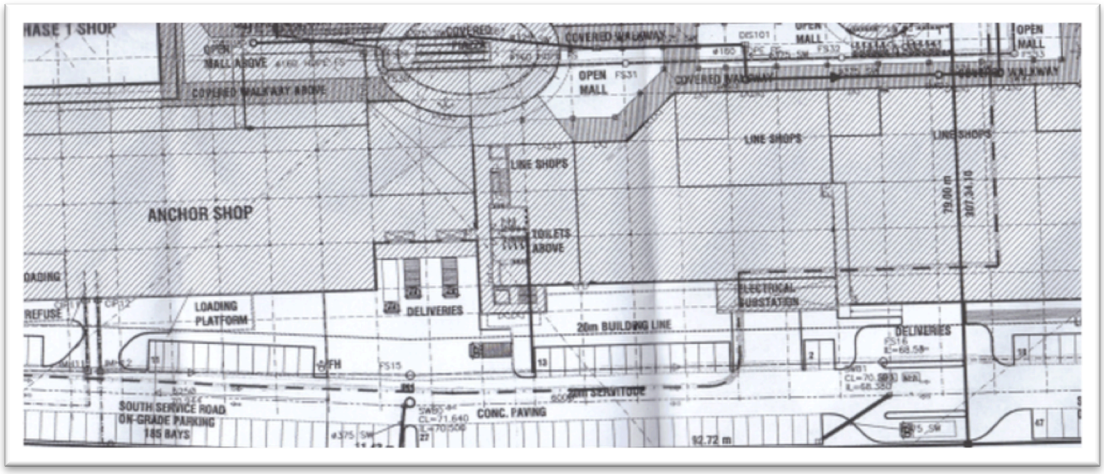


Figure 25: Site4

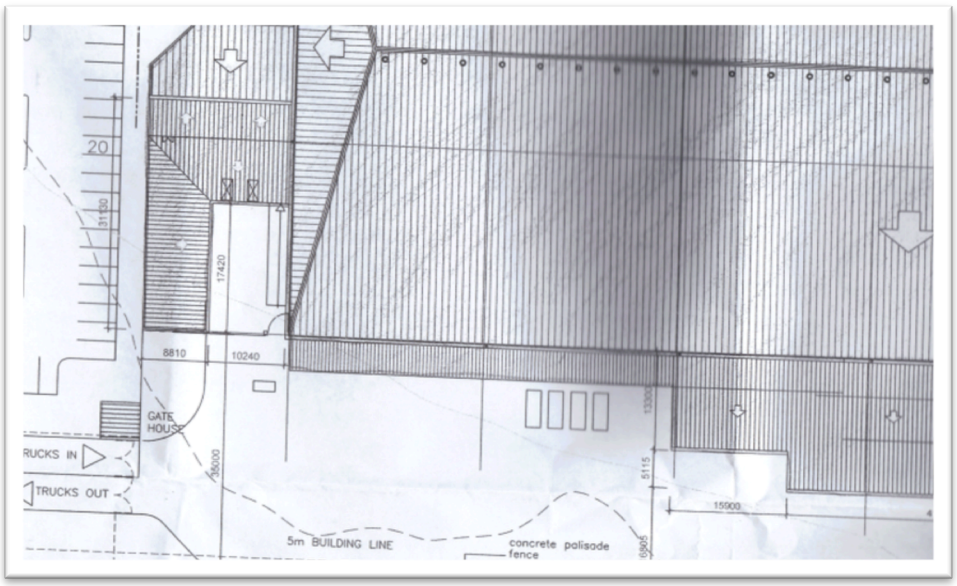
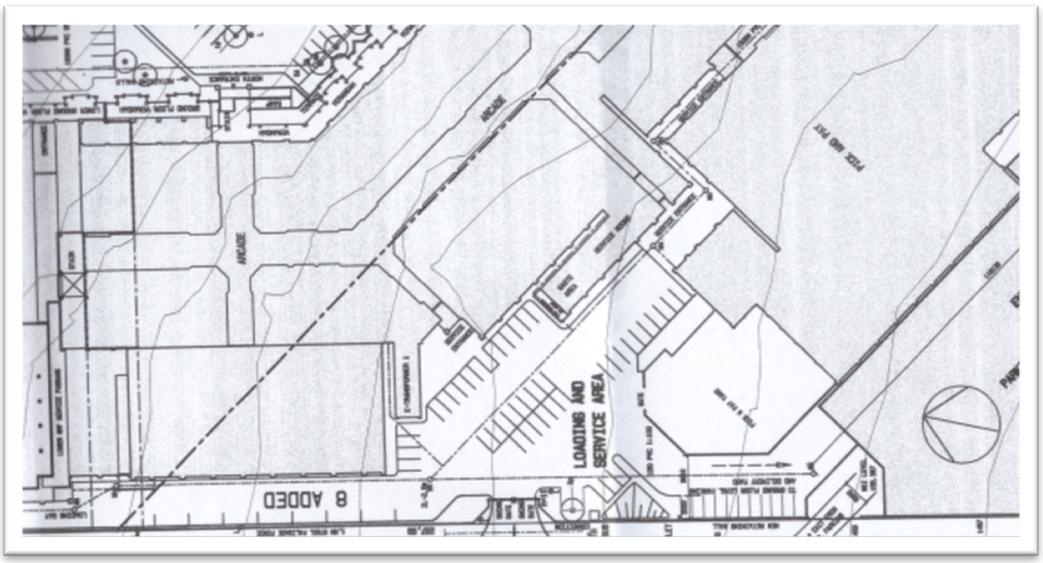


Figure 26: Site 5



Appendix C

Appendix C.1: Time studies of the five sites

Table 9: Irene Mall (site 1) time study

Basic observations of delivery systems											
Place:	Irene Mall										
Weekday:	Friday (approximately 08:00 - 12:00)										
Observers:	Reine Malan and Rossouw van Jaarsveld										
Vehicle	Parking		Loading in Parking		Loading		Total parking time	Total loading time	Reg. No.	Type	Product
	In	Out	Start	End	Start	End					
1					8:10	8:40	0.0	30.0	GP	SU truck	TransFig
2					8:20	9:26	0.0	66.0	MP	WB-15	Alzu
3					8:20	8:54	0.0	34.0	GP	WB-15	Pick n Pay
4			8:40	8:53			0.0	13.0	GP	Bakkie	Meat
5	8:45	8:46	8:46	9:04			1.0	18.0	GP	Bakkie	Electronics
6	8:50	8:53	8:53	9:07			3.0	14.0	GP	Bakkie	BEX
7	8:51	8:53			8:53	9:07	2.0	14.0	GP	WB-15	Bread
8	8:51	9:00			9:00	9:47	9.0	47.0	GP	SU truck	SirJuice
9	8:57	9:02			9:03	10:00	5.0	57.0	GP	Bakkie	Food
10	9:00	9:04			9:04	10:07	4.0	63.0	GP	Bakkie	Cooldrink
11			9:08	9:23			0.0	15.0	GP	Armoured vehicle	Money
12	9:09	9:12	9:12	9:42			3.0	30.0	GP	SU truck	Metrofile
13			9:06	9:17			0.0	11.0	GP	SU truck	Primi
14	9:24	9:34			9:35	11:57	10.0	142.0	GP	WB- 20	Coke
15	9:29	9:52	9:52	10:36			23.0	44.0	GP	SU truck	Mimmos
16			9:30	9:40			0.0	10.0	GP	Minivan	Flowers
17	9:37	10:49			10:51	11:10	72.0	19.0	GP	Bakkie	Boxes
18			9:43	10:01			0.0	18.0	GP	Minivan	Diverse
19			10:00	10:13			0.0	13.0	GP	WB-15	Wine
20			10:03	10:12			0.0	9.0	GP	WB-15	A&S
21			10:03	10:13			0.0	10.0	GP	SU truck	Waltons
22			10:17	10:26			0.0	9.0	GP	Minivan	Diverse
23			10:19	10:36			0.0	17.0	GP	SU truck	FirstFreight
24			10:39	10:47			0.0	8.0	MP	SU truck	Distro Liquor
25			10:42	11:07			0.0	25.0	GP	WB-15	Eggs
26			10:47	11:10			0.0	23.0	GP	SU truck	Water
27					10:55	11:15	0.0	20.0	GP	WB-15	Meat
28					11:03	11:30	0.0	27.0	GP	SU truck	Beans
29	11:03	11:18			11:18	11:59	15.0	41.0	GP	WB- 20	Food
30			11:13	11:26			0.0	13.0	GP	Bakkie	Globes
31			11:13	11:48			0.0	35.0	GP	Bakkie	Diverse

Table 10: Builder's Warehouse (site 2) time study

Basic observations of delivery systems									
Place:	Builder's Warehouse in Centurion								
Weekday:	Thursday (10:00 - 14:20)								
Observers:	Reine Malan and Rossouw van Jaarsveld								
Vehicle	Parking		Loading		Total parking time	Total loading time	Reg. Nr.	Type	Product
	In	Out	In	Out					
1	10:00	10:03	10:04	12:45	3.0	161.0	GP	WB-15	Ryobi
2	10:00	10:09	10:10	11:12	9.0	62.0	GP	WB-15	Value logistics
3			10:02	10:15		13.0	GP	Minivan	Fischer
4			10:03	10:17		14.0	GP	Bakkie	Crafts
5	10:20	10:51	10:53	11:50	31.0	57.0	GP	SU truck	Couriers
6	10:25	12:30	12:35	13:31	125.0	56.0	GP	SU truck	Hardware
7	10:27	13:30	13:36	14:06	183.0	30.0	GP	SU truck	Hardware
8	10:51	12:40	12:42	13:10	109.0	28.0	GP	WB-15	Hardware
9	11:02	13:32	13:34	14:15	150.0	41.0	EC	Bakkie	Pool neccisities
10			11:45	12:00		15.0	GP	Bakkie	Outdoor lights
11			11:45	11:57		12.0	GP	WB-15	Wood
12			11:55	12:30		35.0	GP	WB-15	Afrox
13	12:04	12:59	13:00	13:07	55.0	7.0	GP	WB-15	Plants
14			12:08	12:30		22.0	GP	WB-15	Builders Warehouse
15			12:10	12:19		9.0	GP	Bakkie	Courier IT
16			12:12	12:38		26.0	GP	Bakkie	CHY Couriers
17			12:23	12:31		8.0	GP	SU truck	Maizeyr
18			12:25	12:40		15.0	GP	WB-15	Alpine
19	12:26	14:01	14:03	14:47	95.0	44.0	GP	WB-15	UTI
20			12:30	12:50		20.0	GP	Minivan	Steiner
21			12:34	12:42		8.0	GP	WB-15	TAL
22	12:37	13:36	13:37	15:01	59.0	84.0	GP	WB-15	Hardware
23			12:55	13:04		9.0	GP	SU truck	Freight more
24			13:01	13:10		9.0	EC	SU truck	Richards
25			13:03	13:22		19.0	GP	Bakkie	Tansport JOE
26			13:09	13:37		28.0	GP	WB-15	Gehalte Groei
27			13:10	13:20		10.0	NW	SU truck	Hychem
28			13:21	13:32		11.0	GP	SU truck	Couriers
29			13:45	14:10		25.0	GP	Bakkie	Hardware
30			14:02	14:20		18.0	GP	Minivan	Hardware

Table 11: Lifestyle Centre (site 3) time study

Basic observations of delivery systems											
Place:	Site 3										
Weekday:	Wednesday (7:40 - 10:30)										
Observers:	Reine Malan and Rossouw van Jaarsveld										
Vehicle	Parking		Loading in Parking		Loading		Total parking time	Total loading time	Reg. Nr.	Type	Product
	In	Out	Start	End	Start	End					
1					7:40	7:50	0.0	10.0	GP	SU truck	Blue Ribbon
2	7:40	7:50			7:50	8:34	10.0	44.0	GP	WB-15	Vital DS
3					7:41	8:00	0.0	19.0	GP	Bakkie	Hardware
4					7:42	8:42	0.0	60.0	GP	SU truck	Paint
5	7:50	7:53			7:53	9:11	3.0	78.0	GP	WB-15	Network Africa
6	7:54	8:34			8:34	8:51	40.0	17.0	GP	SU truck	Melba- Milk
7	7:58	8:00			8:00	8:22	2.0	22.0	EC	SU truck	Food
8					8:00	8:28	0.0	28.0	GP	SU truck	Vegetables
9	8:01	8:34			8:34	9:58	33.0	84.0	GP	WB-15	Pick n Pay
10					8:08	8:15	0.0	7.0	GP	Bakkie	Boxes
11	8:10	8:12			8:12	8:35	2.0	23.0	GP	SU truck	Bread
12	8:16	8:38			8:38	9:47	22.0	69.0	GP	WB-15	Pick n Pay
13			8:17	8:40			0.0	23.0	GP	Bakkie	Coating
14					8:28	8:40	0.0	12.0	GP	SU truck	RTT
15					8:30	8:47	0.0	17.0	GP	SU truck	Meat
16	8:30	8:32	8:32	9:22			2.0	50.0	GP	WB-15	KLL
17					8:35	8:47	0.0	12.0	GP	WB-15	Albany
18	8:36	8:38	8:38	9:42			2.0	64.0	GP	SU truck	FamousBrands
19	8:49	8:50	8:50	8:53			1.0	3.0	GP	WB-15	Sunbake
20	8:56	8:59			9:01	9:48	3.0	47.0	GP	WB- 20	Furniture
21	9:01	9:19			9:19	9:42	18.0	23.0	GP	WB-15	Ice-cream
22			9:07	9:12			0.0	5.0	MP	SU	Food
23			9:07	9:16			0.0	9.0	GP	WB-15	Food
24			9:09	9:15			0.0	6.0	GP	SU truck	Food
25	9:27	9:30	9:30	9:49			3.0	19.0	GP	WB-15	Appliances
26					9:32	9:43	0.0	11.0	GP	WB-15	Network Africa
27			9:47	9:56			0.0	9.0	GP	Bakkie	Bread
28			9:47	10:00			0.0	13.0	GP	SU truck	CPAC- Photo
29	9:52	9:53	9:53	10:12			1.0	19.0	GP	WB-15	Hardware
30	10:04	10:09	10:09	10:21			5.0	12.0	GP	Bakkie	Glass
31					10:09	10:30	0.0	21.0	GP	Minivan	Courier

Table 12: Makro (site 4) time study

Basic observations of delivery systems											
Place:	Makro in Centurion										
Weekday:	Tuesday (08:52 - 12:40)										
Observers:	Reine Malan and Willeen Gerryts										
Vehicle	Parking		Loading in Parking		Loading		Total parking time	Total loading time	Reg. Nr.	Type	Product
	In	Out	Start	End	Start	End					
1					8:52	9:11	0.0	19.0	GP	SU truck	
2					8:58	9:10	0.0	12.0	GP	WB-15	Simba
3					9:05	9:15	0.0	10.0	GP	Bakkie	Diverse
4					9:05	9:17	0.0	12.0	GP	Small vehicle	Baking
5					9:06	10:00	0.0	54.0	GP	Bakkie	Diverse
6					9:12	9:17	0.0	5.0	GP	Bakkie	Domestic
7					9:13	9:35	0.0	22.0	GP	SU truck	Appliances
8					9:14	9:24	0.0	10.0	GP	Condor	Hardware
9					9:27	9:52	0.0	25.0	GP	Bakkie	Paper
10					9:29	9:33	0.0	4.0	GP	Bakkie	Diverse
11					9:32	10:31	0.0	59.0	GP	Bakkie	
12					9:33	9:49	0.0	16.0	GP	Small vehicle	Diverse
13					9:40	9:55	0.0	15.0	GP	Bakkie	Diverse
14					9:42	9:50	0.0	8.0	GP	Small vehicle	Diverse
15					9:44	10:00	0.0	16.0	GP	Bakkie	Sugar
16					9:47	10:32	0.0	45.0	GP	Minivan	
17					9:48	10:28	0.0	40.0	EC	Hilux Bakkie	
18			9:49	9:54			0.0	5.0	GP	Minivan	Cannon higiene
19					9:53	9:57	0.0	4.0	GP	Kombi	Cooldrink
20					10:04	10:40	0.0	36.0	GP	Bakkie	Diverse
21					10:06	11:12	0.0	66.0	GP	Small vehicle	Diverse
22					10:09	10:39	0.0	30.0	GP	Small vehicle	Diverse
23					10:09	10:15	0.0	6.0	GP	SU truck	Diverse
24			10:10	10:20			0.0	10.0	GP	Small vehicle	Diverse
25			10:11	10:42			0.0	31.0	EC	Small vehicle	Diverse
26					10:14	10:20	0.0	6.0	GP	Small vehicle	Cooldrink
27			10:16	10:22			0.0	6.0	GP	Bakkie	Diverse
28					10:17	10:23	0.0	6.0	GP	Bakkie	Diverse
29					10:17	10:22	0.0	5.0	GP	WB-15	Diverse
30					10:18	10:30	0.0	12.0	GP	WB-15	Diverse
31					10:32	11:13	0.0	41.0	GP	SU truck	Beverages
32					10:34	12:15	0.0	101.0	GP	Interlink	Simba
33					10:34	10:50	0.0	16.0	GP	Bakkie	Furniture
34					10:34	11:08	0.0	34.0	GP	SU truck	Electronics
35					10:42	11:01	0.0	19.0	GP	Bakkie	Appliances
36			10:43	11:09			0.0	26.0	GP	SU truck	Appliances
37					10:45	11:17	0.0	32.0	GP	Bakkie	Wine
38	10:50	11:11			11:11	12:10	21.0	59.0	GP	WB-15	Imperial
39	10:50	11:11			11:11	11:45	21.0	34.0	GP	SU truck	CMB Couriers
40	11:06	11:15			11:15	12:30	9.0	75.0	GP	WB-15	Supersun
41	11:12	11:16	11:16	11:55			4.0	39.0	GP	SU truck	Blue Ribbon
42	11:13	11:40					27.0	0.0	GP	SU truck	Cooldrinks
43					11:18	12:40	0.0	82.0	GP	WB- 20	Valpre

Table 13: Mall @ Reds (site 5) time study

Basic observations of delivery systems											
Place:	Mall @ Reds										
Weekday:	Monday										
Observers:	Reine Malan and Evert Potgieter										
Vehicle	Parking		Loading in Parking		Loading		Total parking time	Total loading time	Reg. Nr.	Type	Product
	In	Out	Start	End	Start	End					
1					8:25	8:38	0.0	13.0	GP	SU truck	Blue Ribbon
2					8:36	9:09	0.0	33.0	GP	WB-15	Vital DS
3					8:36	9:00	0.0	24.0	GP	Bakkie	Hardware
4			8:37	9:01			0.0	24.0	GP	SU truck	Paint
5					8:41	9:10	0.0	29.0	GP	WB-15	Network Africa
6					8:42	9:30	0.0	48.0	GP	SU truck	Melba- Milk
7					8:51	9:15	0.0	24.0	EC	SU truck	Food
8					8:52	9:20	0.0	28.0	GP	SU truck	Vegetables
9					9:00	10:08	0.0	68.0	GP	WB-15	Pick n Pay
10					9:00	10:10	0.0	70.0	GP	Bakkie	Boxes
11	8:55	10:24			10:24	10:59	89.0	35.0	GP	SU truck	Bread
12					9:03	9:20	0.0	17.0	GP	WB-15	Pick n Pay
13					9:04	10:13	0.0	69.0	GP	Bakkie	Coating
14			9:13	9:15			0.0	2.0	GP	SU truck	RTT
15					9:14	9:22	0.0	8.0	GP	SU truck	Meat
16					9:22	9:34	0.0	12.0	GP	WB-15	KLL
17	9:15	9:23	9:23	9:31			8.0	8.0	GP	WB-15	Albany
18	9:17	9:23			9:24	9:47	6.0	23.0	GP	SU truck	FamousBrands
19					9:29	9:33	0.0	4.0	GP	WB-15	Sunbake
20					9:36	9:51	0.0	15.0	GP	WB- 20	Furniture
21					9:37	9:44	0.0	7.0	GP	WB-15	Ice-cream
22					9:41	10:05	0.0	24.0	MP	SU truck	Food
23					9:54	10:13	0.0	19.0	GP	WB-15	Food
24					9:58	10:04	0.0	6.0	GP	SU truck	Food
25					9:59	10:12	0.0	13.0	GP	WB-15	Appliances
26					10:00	10:11	0.0	11.0	GP	WB-15	Network Africa
27					10:02	10:32	0.0	30.0	GP	Bakkie	Bread
28					10:03	10:17	0.0	14.0	GP	SU truck	CPAC- Photo
29					10:04	10:12	0.0	8.0	GP	WB-15	Hardware
30					10:08	11:03	0.0	55.0	GP	Bakkie	Glass
31	10:17	10:37			10:38	11:20	20.0	42.0	GP	Minivan	Courier
32					10:22	11:00	0.0	38.0	GP	Standard	Unknown
33	10:23	10:40			10:42	11:33	17.0	51.0	GP	Standard	Unknown

Appendix C.2: Service times and the different distributions

Table 14: Loading times at Irene Mall

Loading times	Minutes
Average	28.87
Std Dev	26.56
Sample size	31

Table 15: Service times and the different distributions at Irene Mall

Number	Loading time sorted	Log Values	Cumulative Percentage	Normal Distribution	LogNormal Distribution	Exponential Distribution
1	8.0	2.08	3.1%	21.6%	7.4%	24.2%
2	9.0	2.20	6.3%	22.7%	10.0%	26.8%
3	9.0	2.20	9.4%	22.7%	10.0%	26.8%
4	10.0	2.30	12.5%	23.9%	12.9%	29.3%
5	10.0	2.30	15.6%	23.9%	12.9%	29.3%
6	11.0	2.40	18.8%	25.0%	16.0%	31.7%
7	13.0	2.56	21.9%	27.5%	22.5%	36.3%
8	13.0	2.56	25.0%	27.5%	22.5%	36.3%
9	13.0	2.56	28.1%	27.5%	22.5%	36.3%
10	14.0	2.64	31.3%	28.8%	25.8%	38.4%
11	14.0	2.64	34.4%	28.8%	25.8%	38.4%
12	15.0	2.71	37.5%	30.1%	29.1%	40.5%
13	17.0	2.83	40.6%	32.7%	35.5%	44.5%
14	18.0	2.89	43.8%	34.1%	38.5%	46.4%
15	18.0	2.89	46.9%	34.1%	38.5%	46.4%
16	19.0	2.94	50.0%	35.5%	41.5%	48.2%
17	20.0	3.00	53.1%	36.9%	44.4%	50.0%
18	23.0	3.14	56.3%	41.3%	52.3%	54.9%
19	25.0	3.22	59.4%	44.2%	57.1%	57.9%
20	27.0	3.30	62.5%	47.2%	61.3%	60.7%
21	30.0	3.40	65.6%	51.7%	66.9%	64.6%
22	30.0	3.40	68.8%	51.7%	66.9%	64.6%
23	34.0	3.53	71.9%	57.7%	73.1%	69.2%
24	35.0	3.56	75.0%	59.1%	74.5%	70.2%
25	41.0	3.71	78.1%	67.6%	81.2%	75.8%
26	44.0	3.78	81.3%	71.6%	83.8%	78.2%
27	47.0	3.85	84.4%	75.3%	86.0%	80.4%
28	57.0	4.04	87.5%	85.5%	91.2%	86.1%
29	63.0	4.14	90.6%	90.1%	93.3%	88.7%
30	66.0	4.19	93.8%	91.9%	94.1%	89.8%
31	142.0	4.96	96.9%	100.0%	99.6%	99.3%

Table 16: Loading times at Builder's Warehouse

Loading times	Minutes
Average	29.87
Std Dev	31.20
Sample size	30

Table 17: Service times and the different distributions at Builder's Warehouse

Number	Parking time sorted	Log Values	Cumulative Percentage	Normal Distribution	LogNormal Distribution	Exponential Distribution
1	7.0	1.95	3.2%	23.2%	7.9%	20.9%
2	8.0	2.08	6.5%	24.2%	10.7%	23.5%
3	8.0	2.08	9.7%	24.2%	10.7%	23.5%
4	9.0	2.20	12.9%	25.2%	13.7%	26.0%
5	9.0	2.20	16.1%	25.2%	13.7%	26.0%
6	9.0	2.20	19.4%	25.2%	13.7%	26.0%
7	10.0	2.30	22.6%	26.2%	16.9%	28.5%
8	11.0	2.40	25.8%	27.3%	20.1%	30.8%
9	12.0	2.48	29.0%	28.3%	23.4%	33.1%
10	13.0	2.56	32.3%	29.4%	26.6%	35.3%
11	14.0	2.64	35.5%	30.6%	29.8%	37.4%
12	15.0	2.71	38.7%	31.7%	32.9%	39.5%
13	15.0	2.71	41.9%	31.7%	32.9%	39.5%
14	18.0	2.89	45.2%	35.2%	41.6%	45.3%
15	19.0	2.94	48.4%	36.4%	44.3%	47.1%
16	20.0	3.00	51.6%	37.6%	46.9%	48.8%
17	22.0	3.09	54.8%	40.0%	51.7%	52.1%
18	25.0	3.22	58.1%	43.8%	58.1%	56.7%
19	26.0	3.26	61.3%	45.1%	60.0%	58.1%
20	28.0	3.33	64.5%	47.6%	63.6%	60.8%
21	28.0	3.33	67.7%	47.6%	63.6%	60.8%
22	30.0	3.40	71.0%	50.2%	66.9%	63.4%
23	35.0	3.56	74.2%	56.5%	73.6%	69.0%
24	41.0	3.71	77.4%	63.9%	79.8%	74.7%
25	44.0	3.78	80.6%	67.5%	82.2%	77.1%
26	56.0	4.03	83.9%	79.9%	89.0%	84.7%
27	57.0	4.04	87.1%	80.8%	89.5%	85.2%
28	62.0	4.13	90.3%	84.8%	91.3%	87.5%
29	84.0	4.43	93.5%	95.9%	95.9%	94.0%
30	161.0	5.08	96.8%	100.0%	99.5%	99.5%

Table 18: Loading times at Lifestyle Centre

Loading times	Minutes
Average	26.97
Std Dev	22.92
Sample size	31

Table 19: Service times and the different distributions at Lifestyle Centre

Number	Loading time sorted	Log Values	Cumulative Percentage	Normal	LogNormal	Exponential
1	3.0	1.10	3.1%	14.8%	1.4%	10.5%
2	5.0	1.61	6.3%	16.9%	5.6%	16.9%
3	6.0	1.79	9.4%	18.0%	8.4%	19.9%
4	7.0	1.95	12.5%	19.2%	11.6%	22.9%
5	9.0	2.20	15.6%	21.7%	18.4%	28.4%
6	9.0	2.20	18.8%	21.7%	18.4%	28.4%
7	10.0	2.30	21.9%	23.0%	21.9%	31.0%
8	11.0	2.40	25.0%	24.3%	25.4%	33.5%
9	12.0	2.48	28.1%	25.7%	28.8%	35.9%
10	12.0	2.48	31.3%	25.7%	28.8%	35.9%
11	12.0	2.48	34.4%	25.7%	28.8%	35.9%
12	13.0	2.56	37.5%	27.1%	32.1%	38.2%
13	17.0	2.83	40.6%	33.2%	44.1%	46.8%
14	17.0	2.83	43.8%	33.2%	44.1%	46.8%
15	19.0	2.94	46.9%	36.4%	49.3%	50.6%
16	19.0	2.94	50.0%	36.4%	49.3%	50.6%
17	19.0	2.94	53.1%	36.4%	49.3%	50.6%
18	21.0	3.04	56.3%	39.7%	54.0%	54.1%
19	22.0	3.09	59.4%	41.4%	56.1%	55.8%
20	23.0	3.14	62.5%	43.1%	58.2%	57.4%
21	23.0	3.14	65.6%	43.1%	58.2%	57.4%
22	23.0	3.14	68.8%	43.1%	58.2%	57.4%
23	28.0	3.33	71.9%	51.8%	67.0%	64.6%
24	44.0	3.78	75.0%	77.1%	83.5%	80.4%
25	47.0	3.85	78.1%	80.9%	85.3%	82.5%
26	50.0	3.91	81.3%	84.3%	86.9%	84.3%
27	60.0	4.09	84.4%	92.5%	91.0%	89.2%
28	64.0	4.16	87.5%	94.7%	92.1%	90.7%
29	69.0	4.23	90.6%	96.7%	93.4%	92.3%
30	78.0	4.36	93.8%	98.7%	95.0%	94.5%
31	84.0	4.43	96.9%	99.4%	95.9%	95.6%

Table 20: Loading times at Makro

Loading times	Minutes
Average	27.45
Std Dev	23.68
Sample size	42

Table 21: Service times and the different distributions at Makro

Number	Loading time sorted	Log Values	Cumulative Percentage	Normal	LogNormal	Exponential
1	4.0	1.39	2.3%	16.1%	4.6%	13.6%
2	4.0	1.39	4.7%	16.1%	4.6%	13.6%
3	5.0	1.61	7.0%	17.2%	7.5%	16.7%
4	5.0	1.61	9.3%	17.2%	7.5%	16.7%
5	5.0	1.61	11.6%	17.2%	7.5%	16.7%
6	6.0	1.79	14.0%	18.3%	10.7%	19.6%
7	6.0	1.79	16.3%	18.3%	10.7%	19.6%
8	6.0	1.79	18.6%	18.3%	10.7%	19.6%
9	6.0	1.79	20.9%	18.3%	10.7%	19.6%
10	8.0	2.08	23.3%	20.6%	17.7%	25.3%
11	10.0	2.30	25.6%	23.1%	24.7%	30.5%
12	10.0	2.30	27.9%	23.1%	24.7%	30.5%
13	10.0	2.30	30.2%	23.1%	24.7%	30.5%
14	12.0	2.48	32.6%	25.7%	31.3%	35.4%
15	12.0	2.48	34.9%	25.7%	31.3%	35.4%
16	12.0	2.48	37.2%	25.7%	31.3%	35.4%
17	15.0	2.71	39.5%	30.0%	40.4%	42.1%
18	16.0	2.77	41.9%	31.4%	43.1%	44.2%
19	16.0	2.77	44.2%	31.4%	43.1%	44.2%
20	16.0	2.77	46.5%	31.4%	43.1%	44.2%
21	19.0	2.94	48.8%	36.1%	50.5%	49.9%
22	19.0	2.94	51.2%	36.1%	50.5%	49.9%
23	22.0	3.09	53.5%	40.9%	56.8%	55.1%
24	25.0	3.22	55.8%	45.9%	62.2%	59.8%
25	26.0	3.26	58.1%	47.6%	63.8%	61.2%
26	30.0	3.40	60.5%	54.3%	69.5%	66.5%
27	31.0	3.43	62.8%	56.0%	70.7%	67.7%
28	32.0	3.47	65.1%	57.6%	71.9%	68.8%
29	34.0	3.53	67.4%	60.9%	74.1%	71.0%
30	34.0	3.53	69.8%	60.9%	74.1%	71.0%
31	36.0	3.58	72.1%	64.1%	76.0%	73.1%
32	39.0	3.66	74.4%	68.7%	78.6%	75.8%
33	40.0	3.69	76.7%	70.2%	79.4%	76.7%
34	41.0	3.71	79.1%	71.6%	80.2%	77.5%
35	45.0	3.81	81.4%	77.1%	82.9%	80.6%
36	54.0	3.99	83.7%	86.9%	87.5%	86.0%
37	59.0	4.08	86.0%	90.9%	89.3%	88.3%
38	59.0	4.08	88.4%	90.9%	89.3%	88.3%
39	66.0	4.19	90.7%	94.8%	91.4%	91.0%
40	75.0	4.32	93.0%	97.8%	93.4%	93.5%
41	82.0	4.41	95.3%	98.9%	94.5%	95.0%
42	101.0	4.62	97.7%	99.9%	96.6%	97.5%

Table 22: Loading times at Mall @ Reds

Loading times	Minutes
Average	26.42
Std Dev	19.38
Sample size	33

Table 23: Service times and the different distributions at Mall @ Reds

Number	Loading time sorted	Log Values	Cumulative Percentage	Normal	LogNormal	Exponential
1	2.0	0.69	2.9%	10.4%	0.4%	7.3%
2	4.0	1.39	5.9%	12.4%	3.2%	14.0%
3	6.0	1.79	8.8%	14.6%	8.4%	20.3%
4	7.0	1.95	11.8%	15.8%	11.6%	23.3%
5	8.0	2.08	14.7%	17.1%	14.9%	26.1%
6	8.0	2.08	17.6%	17.1%	14.9%	26.1%
7	8.0	2.08	20.6%	17.1%	14.9%	26.1%
8	11.0	2.40	23.5%	21.3%	25.2%	34.1%
9	12.0	2.48	26.5%	22.8%	28.5%	36.5%
10	13.0	2.56	29.4%	24.4%	31.7%	38.9%
11	13.0	2.56	32.4%	24.4%	31.7%	38.9%
12	14.0	2.64	35.3%	26.1%	34.9%	41.1%
13	15.0	2.71	38.2%	27.8%	37.9%	43.3%
14	17.0	2.83	41.2%	31.3%	43.6%	47.4%
15	19.0	2.94	44.1%	35.1%	48.7%	51.3%
16	23.0	3.14	47.1%	43.0%	57.6%	58.1%
17	24.0	3.18	50.0%	45.0%	59.5%	59.7%
18	24.0	3.18	52.9%	45.0%	59.5%	59.7%
19	24.0	3.18	55.9%	45.0%	59.5%	59.7%
20	24.0	3.18	58.8%	45.0%	59.5%	59.7%
21	28.0	3.33	61.8%	53.2%	66.3%	65.3%
22	29.0	3.37	64.7%	55.3%	67.8%	66.6%
23	30.0	3.40	67.6%	57.3%	69.2%	67.9%
24	33.0	3.50	70.6%	63.3%	73.0%	71.3%
25	35.0	3.56	73.5%	67.1%	75.2%	73.4%
26	38.0	3.64	76.5%	72.5%	78.1%	76.3%
27	42.0	3.74	79.4%	78.9%	81.4%	79.6%
28	48.0	3.87	82.4%	86.7%	85.3%	83.7%
29	51.0	3.93	85.3%	89.8%	86.8%	85.5%
30	55.0	4.01	88.2%	93.0%	88.6%	87.5%
31	68.0	4.22	91.2%	98.4%	92.7%	92.4%
32	69.0	4.23	94.1%	98.6%	92.9%	92.7%
33	70.0	4.25	97.1%	98.8%	93.2%	92.9%

Appendix C.3: Filled- in question lists for the five sites

Question list for delivery services

Place: Site 1_____
Weekday: Friday_____
Observer: Reine Malan _____

7. Are the vehicles able to turn on site and avoid reversing onto or from public roads?

Yes_____

8. Is there minimal interaction between service vehicles and other traffic?

No_____

9. Is there a queue outside as well?

No_____

10. How many vehicles are outside that cannot be accommodated?

_____

11. Loading dock design:

rear	side	Other (explain 6)

- How many loading docks?___5 which we observed____
- How many parking areas?_____
- Description of loading docks (ex. Sawtooth docks, 90 degrees etc.)

There is two delivery areas in front and then a the big shops has their own.

12. Additional data:

There are loads of vehicles delivering from the parking area. Some people tend to take their time and the loading process could be very slow.

Question list for delivery services

Place: Site 2_____
Weekday: Thursday _____
Observer: Reine Malan_____

1. Are the vehicles able to turn on site and avoid reversing onto or from public roads?

No, because of stock taking up space in the delivery area _____

2. Is there minimal interaction between service vehicles and other traffic?

Yes_____

3. Is there a queue outside as well?

Yes_____

4. How many vehicles are outside that cannot be accommodated?

Approximately five at a time_____

5. Loading dock design:

rear	side	Other (explain 6)

- How many loading docks?___6____
- How many parking areas?__Stop outside_____
- Description of loading docks (ex. Sawtooth docks, 90 degrees etc.)

Sawtooth_____

6. Additional data:

There is a very long queue, thus some started to load in the parking area. Others tend to sleep in their vehicles and this could take up a lot of time.
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

Question list for delivery services

Place: Site 3_____
Weekday: Wednesday_____
Observer: Reine Malan_____

1. Are the vehicles able to turn on site and avoid reversing onto or from public roads?

Yes_____

2. Is there minimal interaction between service vehicles and other traffic?

Yes_____

3. Is there a queue outside as well?

Only at one big store_____

4. How many vehicles are outside that cannot be accommodated?

_____

5. Loading dock design:

rear	side	Other (explain 6)

- How many loading docks?_See at number 6_____
- How many parking areas?_____
- Description of loading docks (ex. Sawtooth docks, 90 degrees etc.)

_____

6. Additional data:

The Pick n Pay has its own private place, the Checkers has three loading spaces, and there are a few private places for the smaller shops.
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

Place: Site 4_____
Weekday: Tuesday_____
Observer: Reine Malan_____

1. Are the vehicles able to turn on site and avoid reversing onto or from public roads?

Yes_____

2. Is there minimal interaction between service vehicles and other traffic?

Yes_____

3. Is there a queue outside as well?

Yes_____

4. How many vehicles are outside that cannot be accommodated?

An average of 4_____

5. Loading dock design:

rear	side	Other (explain 6)

- How many loading docks?__4 on the one side and 4 on the other_
- How many parking areas?_____
- Description of loading docks (ex. Sawtooth docks, 90 degrees etc.)

_____

6. Additional data:

They have a very big loading zone, but there are still a few stocks taking up space in the loading area.

Question list for delivery services

Place: Site 5_____
Weekday: Monday_____
Observer: Reine Malan_____

1. Are the vehicles able to turn on site and avoid reversing onto or from public roads?

Yes_____

2. Is there minimal interaction between service vehicles and other traffic?

Yes_____

3. Is there a queue outside as well?

At most 2 at a time_____

4. How many vehicles are outside that cannot be accommodated?

At most 2_____

5. Loading dock design:

rear	side	Other (explain 6)

- How many loading docks?___We observed at 3 different places__
- How many parking areas?_____
- Description of loading docks (ex. Sawtooth docks, 90 degrees etc.)

_____

6. Additional data:

This loading zone is particularly operating well.
_____
_____
_____
_____
_____
_____
_____
_____

Appendix D

Chi- square goodness of fit test

- ***Service times for site 1 with Normal, Log Normal and Exponential distribution as calculated in Microsoft Excel***

Chi square	Site 1						
			10	15	25	50	Max
Normal			23,9%	34,10%	44,20%	75,30%	100%
DF	4						
		n		31			
E1	7,409						
E2	3,162	Time intervals		Expected observations	Number of obs		X
E3	3,131	Less than 10		24%	5	1	0,78327453
E4	9,641	Between 11 and 15		10,20%	7	2	4,65852119
E5	4,309	Between 16 and 25		10%	7	3	4,78095209
		Between 26 and 50		31,10%	8	4	0,27931553
X^2	10,5242218	Greater than 50		13,90%	4	5	0,02215851
P-value	0,97						

Chi square	Site 1						
			10	15	25	50	Max
LogNormal			13,0%	29,90%	57,30%	86,10%	100%
DF	4						
		n		31			
E1	4,03						
E2	5,239	Time intervals		Expected observations	Number of obs		X
E3	8,494	Less than 10		13%	5	1	0,23347395
E4	8,928	Between 11 and 15		16,90%	7	2	0,59192995
E5	4,309	Between 16 and 25		27%	7	3	0,26277796
		Between 26 and 50		28,80%	8	4	0,09645878
X^2	1,20679914	Greater than 50		13,90%	4	5	0,02215851
P-value	0,12						

Chi square	Site 1						
			10	15	25	50	Max
Exponential			29,3%	46,40%	57,90%	80,40%	100%
DF	4						
		n		31			
E1	9,083						
E2	5,301	Time intervals		Expected observations	Number of obs		X
E3	3,565	Less than 10		29%	5	1	1,83539458
E4	6,975	Between 11 and 15		17,10%	7	2	0,54453895
E5	4,309	Between 16 and 25		12%	7	3	3,30974053
		Between 26 and 50		22,50%	8	4	0,15062724
X^2	5,86245982	Greater than 50		13,90%	4	5	0,02215851
P-value	0,79						

The Log Normal distribution has the lowest P-value at site 1.

- ***Service times for site 2 with Normal, Log Normal and Exponential distribution as calculated in Microsoft Excel***

Chi square	Site 2						
		10	15	25	50	Max	
Normal		26,2%	31,70%	43,80%	67,50%	100%	
DF	4						
		n	30				
E1	7,86						
E2	1,65	Time intervals	Expected observations	Number of obs			X
E3	3,63	Less than 10	26%	7		1	0,09409669
E4	7,11	Between 11 and 15	5,50%	6		2	11,4681818
E5	4,17	Between 16 and 25	12%	5		3	0,51705234
		Between 26 and 50	23,70%	7		4	0,00170183
X^2	12,2462365	Greater than 50	13,90%	5		5	0,16520384
P-value	0,98						

Chi square	Site 2						
		10	15	25	50	Max	
LogNormal		16,9%	32,80%	58,00%	82,00%	100%	
DF	4						
		n	30				
E1	5,07						
E2	4,77	Time intervals	Expected observations	Number of obs			X
E3	7,56	Less than 10	17%	7		1	0,73469428
E4	7,2	Between 11 and 15	15,90%	6		2	0,31716981
E5	4,17	Between 16 and 25	25%	5		3	0,86687831
		Between 26 and 50	24,00%	7		4	0,00555556
X^2	2,08950179	Greater than 50	13,90%	5		5	0,16520384
P-value	0,28						

Chi square	Site 2						
		10	15	25	50	Max	
Exponential		35,3%	47,10%	56,70%	77,10%	100%	
DF	4						
		n	30				
E1	10,59						
E2	3,54	Time intervals	Expected observations	Number of obs			X
E3	2,88	Less than 10	35%	7		1	1,21700661
E4	6,12	Between 11 and 15	11,80%	6		2	1,70949153
E5	4,17	Between 16 and 25	10%	5		3	1,56055556
		Between 26 and 50	20,40%	7		4	0,12653595
X^2	4,77879348	Greater than 50	13,90%	5		5	0,16520384
P-value	0,69						

The Log Normal distribution has the lowest P-value at site 2.

- ***Service times for site 3 with Normal, Log Normal and Exponential distribution as calculated in Microsoft Excel***

Chi square	Site 3						
			10	15	25	50	Max
Normal			22,9%	27,10%	43,10%	77,10%	100%
DF	4						
		n		31			
E1	7,099						
E2	1,302	Time intervals		Expected observations	Number of obs		X
E3	4,96	Less than 10		23%	7		1 0,00138062
E4	10,54	Between 11 and 15		4,20%	5		2 10,5032289
E5	4,309	Between 16 and 25		16%	10		3 5,12129032
		Between 26 and 50		34,00%	4		4 4,05802657
X^2	19,7947365	Greater than 50		13,90%	5		5 0,11081016
P-value	1						

Chi square	Site 3						
			10	15	25	50	Max
LogNormal			22,0%	32,10%	58,20%	86,90%	100%
DF	4						
		n		31			
E1	6,82						
E2	3,131	Time intervals		Expected observations	Number of obs		X
E3	8,091	Less than 10		22%	7		1 0,00475073
E4	8,897	Between 11 and 15		10,10%	5		2 1,11566943
E5	4,309	Between 16 and 25		26%	10		3 0,45041169
		Between 26 and 50		28,70%	4		4 2,695359
X^2	4,37700102	Greater than 50		13,90%	5		5 0,11081016
P-value	0,65						

Chi square	Site 3						
			10	15	25	50	Max
Exponential			31,0%	38,20%	57,30%	84,30%	100%
DF	4						
		n		31			
E1	9,61						
E2	2,232	Time intervals		Expected observations	Number of obs		X
E3	5,921	Less than 10		31%	7		1 0,70885536
E4	8,37	Between 11 and 15		7,20%	5		2 3,43271685
E5	4,309	Between 16 and 25		19%	10		3 2,81003901
		Between 26 and 50		27,00%	4		4 2,28158901
X^2	9,34401039	Greater than 50		13,90%	5		5 0,11081016
P-value	0,95						

The Log Normal distribution has the lowest P-value at site 3.

- ***Service times for site 4 with Normal, Log Normal and Exponential distribution as calculated in Microsoft Excel***

Chi square	Site 4						
			10	15	25	50	Max
Normal			23,1%	30,00%	45,90%	77,10%	100%
DF	4						
		n	42				
E1	9,702						
E2	2,898	Time intervals	Expected observations	Number of obs		X	
E3	6,678	Less than 10	23%	13		1	1,12108885
E4	13,104	Between 11 and 15	6,90%	4		2	0,419049
E5	5,838	Between 16 and 25	16%	7		3	0,01552621
		Between 26 and 50	31,20%	11		4	0,33782173
X^2	2,12477116	Greater than 50	13,90%	7		5	0,23128537
P-value	0,29						

Chi square	Site 4						
			10	15	25	50	Max
LogNormal			24,7%	40,40%	62,20%	82,90%	100%
DF	4						
		n	42				
E1	10,374						
E2	6,594	Time intervals	Expected observations	Number of obs		X	
E3	9,156	Less than 10	25%	13		1	0,66472682
E4	8,694	Between 11 and 15	15,70%	4		2	1,02044829
E5	5,838	Between 16 and 25	22%	7		3	0,50768196
		Between 26 and 50	20,70%	11		4	0,61164435
X^2	3,03578678	Greater than 50	13,90%	7		5	0,23128537
P-value	0,44						

Chi square	Site 4						
			10	15	25	50	Max
Exponential			30,5%	42,10%	59,80%	80,60%	100%
DF	4						
		n	42				
E1	12,81						
E2	4,872	Time intervals	Expected observations	Number of obs		X	
E3	7,434	Less than 10	31%	13		1	0,00281811
E4	8,736	Between 11 and 15	11,60%	4		2	0,15607225
E5	5,838	Between 16 and 25	18%	7		3	0,0253371
		Between 26 and 50	20,80%	11		4	0,5867326
X^2	1,00224543	Greater than 50	13,90%	7		5	0,23128537
P-value	0,09						

The Exponential distribution has the lowest P-value at site 4.

- ***Service times for site 5 with Normal, Log Normal and Exponential distribution as calculated in Microsoft Excel***

Chi square	Site 5						
			10	15	25	50	Max
Normal			17,1%	27,80%	45,00%	86,70%	100%
DF	4						
		n		33			
E1	5,643						
E2	3,531	Time intervals		Expected observations	Number of obs		X
E3	5,676	Less than 10		17%	7	1	0,32632447
E4	13,761	Between 11 and 15		10,70%	6	2	1,72641206
E5	4,587	Between 16 and 25		17%	7	3	0,30884003
		Between 26 and 50		41,70%	8	4	2,41182479
X^2	4,81058667	Greater than 50		13,90%	5	5	0,03718531
P-value	0,69						

Chi square	Site 5						
			10	15	25	50	Max
LogNormal			14,9%	37,90%	59,50%	85,30%	100%
DF	4						
		n		33			
E1	4,917						
E2	7,59	Time intervals		Expected observations	Number of obs		X
E3	7,128	Less than 10		15%	7	1	0,88242607
E4	8,514	Between 11 and 15		23,00%	6	2	0,333083
E5	4,587	Between 16 and 25		22%	7	3	0,00229854
		Between 26 and 50		25,80%	8	4	0,03103077
X^2	1,2860237	Greater than 50		13,90%	5	5	0,03718531
P-value	0,14						

Chi square	Site 5						
			10	15	25	50	Max
Exponential			26,1%	43,30%	59,70%	83,70%	100%
DF	4						
		n		33			
E1	8,613						
E2	5,676	Time intervals		Expected observations	Number of obs		X
E3	5,412	Less than 10		26%	7	1	0,30207465
E4	7,92	Between 11 and 15		17,20%	6	2	0,01849471
E5	4,587	Between 16 and 25		16%	7	3	0,46595418
		Between 26 and 50		24,00%	8	4	0,00080808
X^2	0,82451693	Greater than 50		13,90%	5	5	0,03718531
P-value	0,06						

The Exponential distribution has the lowest P-value at site 5.

The Log Normal Distribution is the best fit at the majority of the sites.

Appendix E:

Appendix E.1: Random number generator coding in Visual Basics

```
Option Explicit: Option Base 0
'*****************************************************************
***************
'** Random number generator (Mersenne-Twister)
'*****************************************************************
***************
'-- Constants -------------------------------------------------
---------------
Const KRanN0 As Long = 624
Const KRanM0 As Long = 397
Const KRanMN As Long = KRanM0 - KRanN0
Const KRanN1 As Long = KRanN0 - 1
Const KRanM1 As Long = KRanM0 - 1
Const KRanN2 As Long = KRanN0 + 1
Const KRanN3 As Long = KRanN1 - 1
Const KRanNX As Long = KRanN1 - KRanM0
Const KRan01 As Long = 2
Const KRan07 As Long = 128
Const KRan08 As Long = 256
Const KRan11 As Long = 2048
Const KRan15 As Long = 32768
Const KRan16 As Long = 65536
Const KRan18 As Long = 262144
Const KRan24 As Long = 16777216
Const KRan30 As Long = 1073741824
Const DRan31 As Double = 2147483648#
Const DRan32 As Double = 2# * DRan31
Const DRan31Tst As Double = DRan31 - 1#
Const DRan31Neg As Double = 0# - DRan31
Const DRanGap As Double = 0.00000000000005
Const DRanFac As Double = (1# - 2# * DRanGap) / (DRan32 - 1#)
Const KRanMask0 As Long = &H9908B0DF
Const KRanMask1 As Long = &H7FFFFFFF
Const KRanMask2 As Long = &H80000000
'
'-- Variables ---------------------------------------------------
---------------
Dim NRanMT(0 To KRanN1) As Long
Dim KRanMT(2) As Long
Dim IRanMT As Long
'
'-- Normal deviate -----------------------------------------------
---------------
Dim KNorExtra As Long
Dim DNorExtra As Double
'
'-----------------------------------------------------------------
---------------
'-- Function to initialize
'-----------------------------------------------------------------
---------------
Function RANFirst() As Double
    Call RANInit
    RANFirst = RANNumb
End Function
'
'-----------------------------------------------------------------
---------------
'-- Initialize random numbers
'-----------------------------------------------------------------
---------------
Sub RANInit()
Dim DD As Long
NRanMT(0) = (5489 And &HFFFFFFFF)
For IRanMT = 1 To KRanN1
    DD = NRanMT(IRanMT - 1)
NRanMT(IRanMT) = RANAddL(RANMulL(1812433253, _
```

```
        (DD Xor RANDivL(DD, KRan30))), IRanMT)
Next
    IRanMT = KRanN1: KRanMT(0) = 0: KRanMT(1) = KRanMask0
End Sub
'
'-----------------------------------------------------------------
---------------
'-- Random number (0.0 and 1.0 excluded)
'-----------------------------------------------------------------
---------------
Function RANNumb() As Double
Dim II As Long, NN As Long, DD As Double
If IRanMT >= KRanN0 Then
    For II = 0 To KRanNX
        NN = (NRanMT(II) And KRanMask2) Or (NRanMT(II + 1) And
KRanMask1)
NRanMT(II) = (NRanMT(II + KRanM0) Xor _
RANDivL(NN, KRan01)) Xor KRanMT(NN And &H1)
    Next II
    For II = II To KRanN3
        NN = (NRanMT(II) And KRanMask2) Or (NRanMT(II + 1) And
KRanMask1)
NRanMT(II) = (NRanMT(II + KRanMN) Xor _
RANDivL(NN, KRan01)) Xor KRanMT(NN And &H1)
    Next II
    NN = (NRanMT(KRanN1) And KRanMask2) Or (NRanMT(0) And
KRanMask1)
NRanMT(KRanN1) = (NRanMT(KRanM1) Xor _
RANDivL(NN, KRan01)) Xor KRanMT(NN And &H1)
    IRanMT = 0
End If
    NN = NRanMT(IRanMT): IRanMT = IRanMT + 1
    NN = (NN Xor RANDivL(NN, KRan11))
    NN = (NN Xor RANMulL(NN, KRan07) And &H9D2C5680)
    NN = (NN Xor RANMulL(NN, KRan15) And &HEFC60000)
    NN = (NN Xor RANDivL(NN, KRan18))
    If NN < 0 Then
        DD = NN + DRan32
    Else
        DD = NN
    End If
    RANNumb = DRanGap + (DD * DRanFac)
End Function
'
'-----------------------------------------------------------------
---------------
'-- Add two long integers
'-----------------------------------------------------------------
---------------
Function RANAddL(ByVal X1 As Long, ByVal X2 As Long) As Long
Dim DD As Double
    DD = CDbl(X1) + X2
If DD < DRan31Neg Then
    RANAddL = CLng(DRan32 + DD)
Else
    If DD > DRan31Tst Then
        RANAddL = CLng(DD - DRan32)
    Else
        RANAddL = CLng(DD)
    End If
End If
End Function
'
'-----------------------------------------------------------------
---------------
'-- Multiply two long integers, Returns lowest 4 bytes
'-----------------------------------------------------------------
---------------
Function RANMulL(ByVal X1 As Long, ByVal X2 As Long) As Long
Dim DD As Double
Dim A1 As Long, B1 As Long, C1 As Long
Dim A2 As Long, B2 As Long, C2 As Long
Dim R0 As Long, R1 As Long, R2 As Long, R3 As Long
    A1 = (X1 \ KRan16) Mod KRan08
    B1 = (X1 \ KRan08) Mod KRan08: C1 = X1 Mod KRan08
    A2 = (X2 \ KRan16) Mod KRan08
    B2 = (X2 \ KRan08) Mod KRan08: C2 = X2 Mod KRan08
```

```
    R0 = C1 * C2
    R1 = B1 * C2 + C1 * B2 + R0 \ KRan08
    R2 = A1 * C2 + B1 * B2 + C1 * A2 + R1 \ KRan08
    R3 = (((X1 \ KRan24) * C2 + A1 * B2 + B1 * A2 + _
        C1 * (X2 \ KRan24)) Mod KRan08) + R2 \ KRan08
    DD = CDbl(R3 Mod KRan08) * KRan24 + (R2 Mod KRan08) * KRan16
+ _
        (R1 Mod KRan08) * KRan08 + (R0 Mod KRan08)
If DD < DRan31Neg Then
    RANMulL = CLng(DRan32 + DD)
Else
    If DD > DRan31Tst Then
        RANMulL = CLng(DD - DRan32)
    Else
        RANMulL = CLng(DD)
    End If
End If
End Function
'
'-----------------------------------------------------------------
---------------
'-- Divide two long integers, returns as a long integer
'-----------------------------------------------------------------
---------------
Private Function RANDivL(ByVal X1 As Long, ByVal X2 As Long) As
Long
    If X1 < 0 Then
        RANDivL = CLng(Fix((DRan32 + X1) / X2))
    Else
        RANDivL = CLng(Fix(X1 / X2))
    End If
End Function
'
'-----------------------------------------------------------------
---------------
'-- Divide two double numbers, return double number
'-----------------------------------------------------------------
---------------
Private Function RANDivD(ByVal D1 As Double, ByVal D2 As Long) As
Double
    If D1 < 0# Then
        RANDivD = Fix((DRan32 + D1) / D2)
    Else
        RANDivD = Fix(D1 / D2)
    End If
End Function
'
'-----------------------------------------------------------------
---------------
'-- RANNorm - Normal deviate (Marsaglia polar method)
'-----------------------------------------------------------------
---------------
Function RANNorm()
Dim RRan As Double, RFac As Double
'
'-- Generate Normal Deviate -----------------------------------
---------------
    If KNorExtra <> 0 Then GoTo X5
X1: RRan = 2# * RANNumb - 1#
    DNorExtra = 2# * RANNumb - 1#
    RFac = RRan * RRan + DNorExtra * DNorExtra
    If RFac >= 1# Then GoTo X1
    RFac = Sqr(-2# * Log(RFac) / RFac)
    RRan = RRan * RFac
    DNorExtra = DNorExtra * RFac
'
'-- Use first generated normal deviate ------------------------
---------------
    RANNorm = RRan
    KNorExtra = 1
    Exit Function
'
'-- Use second generated normal deviate -----------------------
---------------
X5: RANNorm = DNorExtra
    KNorExtra = 0
End Function
```

```
'
'-------------------------------------------------------------------------
---------------
'-- RANExpo - Exponential distribution
'-------------------------------------------------------------------------
---------------
Function RANExpo(Avg As Double)
    RANExpo = -Log(1# - RANNumb()) * Avg
End Function
```

Appendix E.2: Main program coding in Visual Basics

```
Option Explicit: Option Base 1
'*****************************************************************************
'  Main control program
'*****************************************************************************
'--  General variables ------------------------------------------------------
Public XData As Worksheet, IRow As Long, HCalc As String
Public NChan As Long, IChan As Long, JChan As Long
Public KArrv As Integer, AArrv As Double, SArrv As Double
Public KServ As Integer, AServ As Double, SServ As Double
Public KMove As Integer, AMove As Double, SMove As Double
Public AArrvQ As Double, SArrvQ As Double
Public AServQ As Double, SServQ As Double
Public AMoveQ As Double, SMoveQ As Double
Public AArrvS As Double, SArrvS As Double
Public AServS As Double, SServS As Double
Public AMoveS As Double, SMoveS As Double
Public DelayS As Double, AQueuS As Double, PQueuS(3) As Double
Public DelayQ As Double, AQueuQ As Double, PQueuQ(3) As Double
Public PQueue(3) As Double, IQueue As Long
'
'-----------------------------------------------------------------------------
'  Simulation program
'-----------------------------------------------------------------------------
Sub Simulate()
Dim HH As String
'
'-- Initialize -------------------------------------------------------------
    Set XData = ActiveSheet
PQueue(1) = 0.9: PQueue(2) = 0.95: PQueue(3) = 0.99
    IRow = 4
'
'-- Load data --------------------------------------------------------------
X0: IRow = IRow + 1
    Call StatMesg("Simulation")
    If Not DataLoad() Then GoTo X9
    If HCalc <> "X" Then GoTo X0
XData.Range(XData.Cells(IRow, 12), XData.Cells(IRow, 22)).ClearContents
    Call RANInit
'
'-- Perform simulation -----------------------------------------------------
    If Not SimMod() Then GoTo X5
XData.Cells(IRow, 12) = (AServS + AMoveS) / AArrvS
XData.Cells(IRow, 13) = DelayS: XData.Cells(IRow, 14) = AQueuS
XData.Cells(IRow, 15) = PQueuS(1): XData.Cells(IRow, 16) = PQueuS(2)
XData.Cells(IRow, 17) = PQueuS(3)
'
'-- Queueing model ---------------------------------------------------------
X5: If Not QueMod() Then GoTo X0
XData.Cells(IRow, 18) = DelayQ: XData.Cells(IRow, 19) = AQueuQ
XData.Cells(IRow, 20) = PQueuQ(1): XData.Cells(IRow, 21) = PQueuQ(2)
XData.Cells(IRow, 22) = PQueuQ(3)
    GoTo X0
'
'-- Terminate --------------------------------------------------------------
X9: Call StatMesg("Ready")
End Sub
'
'-----------------------------------------------------------------------------
'  Display status
'-----------------------------------------------------------------------------
Sub StatMesg(HMesg As String)
```

```
    Application.StatusBar = HMesg: DoEvents
End Sub
```

Appendix E.3: Load data coding in Visual Basics

```
Option Explicit: Option Base 1
'*****************************************************************************
'  LOAD DATA
'*****************************************************************************
'-----------------------------------------------------------------------------
'  Data load program
'-----------------------------------------------------------------------------
Function DataLoad() As Boolean
Dim HH As String, TT As Double
'
'-- Load number of channels and distribution types ---------------------------
    HCalc = UCase(Trim(XData.Cells(IRow, 1)))
    If Len(XData.Cells(IRow, 2)) = 0 Then GoTo X9
    NChan = XData.Cells(IRow, 2)
    If NChan < 1 Then NChan = 1
    If NChan > 99 Then NChan = 99
XData.Cells(IRow, 2) = NChan
    HH = UCase(Trim(XData.Cells(IRow, 3))): If Len(HH) = 0 Then GoTo X9
    If HH = "E" Then
        KArrv = 1
    ElseIf HH = "N" Then
        KArrv = 2
    ElseIf HH = "L" Then
        KArrv = 3
    Else
        KArrv = 1: HH = "E"
    End If
XData.Cells(IRow, 3) = HH
    HH = UCase(Trim(XData.Cells(IRow, 4))): If Len(HH) = 0 Then GoTo X9
    If HH = "E" Then
        KServ = 1
    ElseIf HH = "N" Then
        KServ = 2
    ElseIf HH = "L" Then
        KServ = 3
    Else
        KServ = 1: HH = "E"
    End If
XData.Cells(IRow, 4) = HH
    HH = UCase(Trim(XData.Cells(IRow, 5))): If Len(HH) = 0 Then GoTo X9
    If HH = "X" Then
        KMove = 0
    ElseIf HH = "E" Then
        KMove = 1
    ElseIf HH = "N" Then
        KMove = 2
    ElseIf HH = "L" Then
        KMove = 3
    Else
        KMove = 0: HH = "X"
    End If
XData.Cells(IRow, 5) = HH
'
'-- Load parameters ----------------------------------------------------------
    AArrv = XData.Cells(IRow, 6): SArrv = XData.Cells(IRow, 7)
    AServ = XData.Cells(IRow, 8): SServ = XData.Cells(IRow, 9)
    AMove = XData.Cells(IRow, 10): SMove = XData.Cells(IRow, 11)
    AArrvQ = AArrv: SArrvQ = SArrv
    AServQ = AServ: SServQ = SServ
    AMoveQ = AMove: SMoveQ = SMove
    TT = (AServ + AMove) / NChan + 0.1: If AArrv < TT Then AArrv = TT
    If KArrv = 3 Then
        SArrv = Log(1# + SArrv * SArrv / (AArrv * AArrv))
        AArrv = Log(AArrv) - 0.5 * SArrv
        SArrv = Sqr(SArrv)
    End If
    If KServ = 3 Then
        SServ = Log(1# + SServ * SServ / (AServ * AServ))
        AServ = Log(AServ) - 0.5 * SServ
        SServ = Sqr(SServ)
```

```
    End If
    If KMove = 3 Then
        SMove = Log(1# + SMove * SMove / (AMove * AMove))
        AMove = Log(AMove) - 0.5 * SMove
        SMove = Sqr(SMove)
    End If
'
'-- Terminate ----------------------------------------------------------
    DataLoad = True: Exit Function
X9: DataLoad = False
End Function
```

Appendix E.4: Simulation model coding in Visual Basics

```
Option Explicit: Option Base 1
'*************************************************************************
'  Simulation model
'*************************************************************************
Dim NQueu As Long, NArrv As Long, NServ As Long, NMove As Long
Dim NDelay As Long, TPrev As Double, TArrv As Double, TDept As Double
Dim TQueu(0 To 2000) As Double, PXCum As Double, PPCum As Double
Dim KChan(99) As Integer, TChan(99) As Double
Dim PP As Double, TT As Double, II As Long
'
'*************************************************************************
' Simulation Model
'*************************************************************************
Function SimMod() As Boolean
    SimMod = SimulN()
End Function
'
'*************************************************************************
' 1-Channel Simulation Model
'*************************************************************************
Function Simul1() As Boolean
'
'-- Initialize ---------------------------------------------------------
    NQueu = 0: NArrv = 0: NServ = 0: NMove = 0
    AArrvS = 0#: AServS = 0#: AMoveS = 0#
    SArrvS = 0#: SServS = 0#: SMoveS = 0#
    DelayS = 0#: NDelay = 0
    TPrev = 0#: TArrv = 0#: TDept = 0#
    For II = 0 To 2000
TQueu(II) = 0#
    Next II
'
'-- Determine next event -----------------------------------------------
E0: If NDelay > 5000000 Then GoTo X9
    If NQueu = 0 Then GoTo A0
    If TArrv > TDept Then GoTo D0
'
'-- Vehicle arrives, Generate a new arrival ----------------------------
A0: If NQueu >= 2000 Then GoTo X9
    TT = TArrv - TPrev
TQueu(NQueu) = TQueu(NQueu) + TT
    DelayS = DelayS + NQueu * TT
    TPrev = TArrv
    Call SimArrv(TT)
    NQueu = NQueu + 1
    TArrv = TArrv + TT
    NArrv = NArrv + 1
    AArrvS = AArrvS + TT
    SArrvS = SArrvS + TT * TT
    If NQueu > 1 Then GoTo E0
    TDept = TPrev
    GoTo D5
'
'-- Vehicle departs, Set new service time ------------------------------
D0: If NDelay Mod 50000 = 0 Then StatMesg ("Simul1 "& NDelay)
    NDelay = NDelay + 1
    TT = TDept - TPrev
TQueu(NQueu) = TQueu(NQueu) + TT
    DelayS = DelayS + NQueu * TT
    TPrev = TDept
    NQueu = NQueu - 1
```

```
    If NQueu = 0 Then GoTo C0
    Call SimMove(TT)
    TDept = TDept + TT
    NMove = NMove + 1
    AMoveS = AMoveS + TT
    SMoveS = SMoveS + TT * TT
D5: Call SimServ(TT)
    TDept = TDept + TT
    NServ = NServ + 1
    AServS = AServS + TT
    SServS = SServS + TT * TT
    GoTo E0
'
'-- Channel becomes empty ------------------------------------------------------
C0: If NQueu > 0 Then GoTo E0
    If NDelay < 500000 Then GoTo A0
'
'-- Calculate percentile queue lengths ------------------------------------------
Q0: PPCum = 0#
    IQueue = 1
    AQueuS = 0#
For II = 0 To 2000
    If TQueu(II) = 0# Then GoTo Q6
    PP = TQueu(II) / TPrev
    PXCum = PPCum
    PPCum = PPCum + PP
    AQueuS = AQueuS + PP * II
Q5: If IQueue > 3 Then GoTo Q6
    If PQueue(IQueue) > PPCum Then GoTo Q6
PQueuS(IQueue) = II + (PQueue(IQueue) - PPCum) / (PPCum - PXCum)
    IQueue = IQueue + 1
    GoTo Q5
Q6: Next II
    If IQueue <= 3 Then GoTo X9
'
'-- Calculate other results -----------------------------------------------------
    If NMove <= 0 Then NMove = 1
    AArrvS = AArrvS / NArrv: AMoveS = AMoveS / NMove: AServS = AServS / NServ
    SArrvS = Sqr(SArrvS / NArrv - AArrvS * AArrvS)
    SMoveS = Sqr(SMoveS / NMove - AMoveS * AMoveS)
    SServS = Sqr(SServS / NServ - AServS * AServS)
    DelayS = DelayS / NDelay: Simul1 = True: Exit Function
X9: Simul1 = False
End Function
'
'*******************************************************************************
' N-Channel Simulation Model
'*******************************************************************************
Function SimulN() As Boolean
'
'-- Initialize ------------------------------------------------------------------
    NQueu = 0: NArrv = 0: NServ = 0: NMove = 0
    AArrvS = 0#: AServS = 0#: AMoveS = 0#
    SArrvS = 0#: SServS = 0#: SMoveS = 0#
    DelayS = 0#: NDelay = 0
    TPrev = 0#: TArrv = 0#: TDept = 0#
For II = 0 To 2000
TQueu(II) = 0#
Next II
For IChan = 1 To NChan
KChan(IChan) = 0
TChan(IChan) = 0#
Next IChan
'
'-- Determine next event --------------------------------------------------------
E0: If NDelay > 5000000 Then GoTo X9
    If NQueu = 0 Then GoTo A0
    IChan = 0
For JChan = 1 To NChan
    If KChan(JChan) = 0 Then GoTo E6
    If IChan = 0 Then GoTo E5
    If TDept <= TChan(JChan) Then GoTo E6
E5: TDept = TChan(JChan)
    IChan = JChan
E6: Next JChan
    If IChan = 0 Then GoTo X9
    If TArrv > TDept Then GoTo D0
```

```
'
'-- Vehicle arrives, Generate a new arrival -----------------------------------
A0: If NQueu >= 2000 Then GoTo X9
    TT = TArrv - TPrev
TQueu(NQueu) = TQueu(NQueu) + TT
    DelayS = DelayS + NQueu * TT
    TPrev = TArrv
    Call SimArrv(TT)
    TArrv = TArrv + TT
    NQueu = NQueu + 1
    NArrv = NArrv + 1
    AArrvS = AArrvS + TT
    SArrvS = SArrvS + TT * TT
    If NQueu > NChan Then GoTo E0
    TDept = TPrev
For IChan = 1 To NChan
    If KChan(IChan) = 0 Then GoTo D5
Next IChan
    GoTo X9
'
'-- Vehicle departs, Set new service time ----------------------------------
D0: If NDelay Mod 50000 = 0 Then StatMesg ("SimulN "& NDelay)
    NDelay = NDelay + 1
    TT = TDept - TPrev
TQueu(NQueu) = TQueu(NQueu) + TT
    DelayS = DelayS + NQueu * TT
    TPrev = TDept
    NQueu = NQueu - 1
    If NQueu < NChan Then GoTo C0
    Call SimMove(TT)
    TDept = TDept + TT
    NMove = NMove + 1
    AMoveS = AMoveS + TT
    SMoveS = SMoveS + TT * TT
D5: Call SimServ(TT)
KChan(IChan) = 1
TChan(IChan) = TDept + TT
    NServ = NServ + 1
    AServS = AServS + TT
    SServS = SServS + TT * TT
    GoTo E0
'
'-- Channel becomes empty -------------------------------------------------
C0: KChan(IChan) = 0
    If NQueu > 0 Then GoTo E0
    If NDelay < 500000 Then GoTo A0
'
'-- Calculate percentile queue lengths ------------------------------------
Q0: PPCum = 0#
    IQueue = 1
    AQueuS = 0#
For II = 0 To 2000
    If TQueu(II) = 0# Then GoTo Q6
    PP = TQueu(II) / TPrev
    PXCum = PPCum
    PPCum = PPCum + PP
    AQueuS = AQueuS + PP * II
Q5: If IQueue > 3 Then GoTo Q6
    If PQueue(IQueue) > PPCum Then GoTo Q6
PQueuS(IQueue) = II + (PQueue(IQueue) - PPCum) / (PPCum - PXCum)
    IQueue = IQueue + 1
    GoTo Q5
Q6: Next II
    If IQueue <= 3 Then GoTo X9
'
'-- Calculate other results -----------------------------------------------
    If NMove <= 0 Then NMove = 1
    AArrvS = AArrvS / NArrv: AServS = AServS / NServ: AMoveS = AMoveS / NMove
    SArrvS = Sqr(SArrvS / NArrv - AArrvS * AArrvS)
    SServS = Sqr(SServS / NServ - AServS * AServS)
    SMoveS = Sqr(SMoveS / NMove - AMoveS * AMoveS)
    DelayS = DelayS / NDelay: SimulN = True: Exit Function
X9: SimulN = False
End Function
'
'-------------------------------------------------------------------------------
'  Arrival Time Generator
```

```
'-------------------------------------------------------------------------------
Sub SimArrv(TT As Double)
    If KArrv = 1 Then
        TT = RANExpo(AArrv)
        Exit Sub
    End If
    TT = AArrv + SArrv * RANNorm()
    If KArrv = 3 Then TT = Exp(TT)
End Sub
'
'-------------------------------------------------------------------------------
'  Service Time Generator
'-------------------------------------------------------------------------------
Sub SimServ(TT As Double)
    If KServ = 1 Then
        TT = RANExpo(AServ)
        Exit Sub
    End If
    TT = AServ + SServ * RANNorm()
    If KServ = 3 Then TT = Exp(TT)
End Sub
'
'-------------------------------------------------------------------------------
'  Move-up Time Generator
'-------------------------------------------------------------------------------
Sub SimMove(TT As Double)
    If KMove = 0 Then
        TT = 0#
        Exit Sub
    End If
    If KMove = 1 Then
        TT = RANExpo(AMove)
        Exit Sub
    End If
    TT = AMove + SMove * RANNorm()
    If KMove = 3 Then TT = Exp(TT)
End Sub
```

Appendix E.5: Queuing system coding in Visual Basics

```
Option Explicit: Option Base 1
'*******************************************************************************
'  Queuing System
'*******************************************************************************
Dim PXCum As Double, PPCum As Double
Dim QQ As Double, CC As Double
Dim XX As Double, XN As Double
Dim P0 As Double, PP As Double
Dim DD As Double, FF As Double
Dim EE As Double, II As Long
'
'*******************************************************************************
' Queuing System
'*******************************************************************************
Function QueMod() As Boolean
    'If KArrv > 1 Or KServ > 1 Or KMove > 1 Then GoTo X9
    If NChan = 1 Then
        QueMod = QueMM1()
    Else
        QueMod = QueMMN()
    End If
    Exit Function
X9: QueMod = False
End Function
'
'*******************************************************************************
' M/M/1 Queuing System
'*******************************************************************************
Function QueMM1() As Boolean
'
'-- Average queue length and delay ------------------------------------------
    QQ = 1# / AArrvQ: CC = 1# / (AMoveQ + AServQ)
    XX = QQ / CC: If XX >= 1# Then GoTo X9
    P0 = 1# - XX: AQueuQ = XX / P0: DelayQ = AQueuQ / QQ
'
```

```
'-- Calculate percentile queue lengths ----------------------------------------
    IQueue = 1
    PPCum = P0
    II = 0: DD = 1#
Q0: II = II + 1
    DD = DD * XX: PP = P0 * DD
    PXCum = PPCum: PPCum = PPCum + PP
    If PQueue(IQueue) > PPCum Then GoTo Q0
PQueuQ(IQueue) = II + (PQueue(IQueue) - PPCum) / (PPCum - PXCum)
    IQueue = IQueue + 1: If IQueue <= 3 Then GoTo Q0
'
'-- Terminate --------------------------------------------------------------
    QueMM1 = True: Exit Function
X9: QueMM1 = False
End Function
'
'*************************************************************************
' M/M/N Queuing System
'*************************************************************************
Function QueMMN() As Boolean
'
'-- Average queue length and delay -----------------------------------------
    QQ = 1# / AArrvQ: CC = 1# / (AMoveQ + AServQ)
    XX = QQ / CC: XN = 1# - XX / NChan
    If XN >= 1# Then GoTo X9
    P0 = 1#: DD = 1#: FF = 1#
For II = 1 To NChan - 1
    DD = DD * XX: FF = FF * II: P0 = P0 + DD / FF
Next II
    DD = DD * XX: FF = FF * NChan: P0 = 1# / (P0 + DD / (FF * XN))
    DD = DD * XX: AQueuQ = DD * P0 / (NChan * FF * XN * XN) + XX
    DelayQ = AQueuQ / QQ
'
'-- Calculate percentile queue lengths ----------------------------------------
    IQueue = 1
    PPCum = P0
    II = 0: DD = 1#: FF = 1#: EE = 1#
Q0: II = II + 1
    DD = DD * XX
    If II <= NChan Then
        FF = FF * II: PP = P0 * DD / FF
    Else
        EE = EE * NChan: PP = P0 * DD / (FF * EE)
    End If
    PXCum = PPCum: PPCum = PPCum + PP
    If PQueue(IQueue) > PPCum Then GoTo Q0
PQueuQ(IQueue) = II + (PQueue(IQueue) - PPCum) / (PPCum - PXCum)
    IQueue = IQueue + 1: If IQueue <= 3 Then GoTo Q0
'
'-- Terminate --------------------------------------------------------------
    QueMMN = True: Exit Function
X9: QueMMN = False
End Function
```

Appendix F:

Table 24: Verification of simulation model with exponential distributions

Offloading simulation - Verification of simulation model - Exponential																					
	No of	Distributions			Parameters						Traffic	Simulation					Queuing theory				
X	Chan-nels	Arrival Distr	Service Distr	Moveup Distr	Avg Arrival	Std Dev Arrival	Avg Service	Std Dev Service	Avg Moveup	Std Dev Moveup	Ratio (%)	Avg Delay	Avg Queue	90% Queue	95% Queue	99% Queue	Avg Delay	Avg Queue	90% Queue	95% Queue	99% Queue
X	1	E	E	X	6000.0		1800.0		0.0		30%	2571	0.43	0.95	1.63	2.90	2571	0.43	0.95	1.63	2.90
X	1	E	E	X	3600.0		1800.0		0.0		50%	3591	1.00	2.39	3.39	5.70	3600	1.00	2.40	3.40	5.72
X	1	E	E	X	2250.0		1800.0		0.0		80%	8939	3.98	9.28	12.34	19.34	9000	4.00	9.34	12.45	19.66
X	2	E	E	X	3000.0		1800.0		0.0		60%	1975	0.66	1.39	1.91	3.26	1978	0.66	1.40	1.71	3.28
X	2	E	E	X	1800.0		1800.0		0.0		100%	2383	1.32	2.78	3.77	5.95	2400	1.33	2.80	3.80	6.08
X	2	E	E	X	1125.0		1800.0		0.0		160%	4952	4.40	9.70	12.78	20.02	5000	4.44	9.81	12.91	20.12
X	5	E	E	X	1200.0		1800.0		0.0		150%	1810	1.51	2.74	3.36	4.71	1810	1.51	2.74	3.36	4.72
X	5	E	E	X	720.0		1800.0		0.0		250%	1891	2.63	4.45	5.44	7.72	1894	2.63	4.47	5.47	7.77
X	5	E	E	X	450.0		1800.0		0.0		400%	2762	6.14	11.50	14.42	21.37	2797	6.22	11.70	14.80	21.99
X	10	E	E	X	600.0		1800.0		0.0		300%	1800	3.00	4.84	5.66	7.19	1800	3.00	4.84	5.67	7.24
X	10	E	E	X	360.0		1800.0		0.0		500%	1812	5.04	7.56	8.59	10.85	1813	5.04	7.57	8.62	10.89
X	10	E	E	X	225.0		1800.0		0.0		801%	2171	9.66	15.36	18.40	26.01	2168	9.64	15.34	18.45	25.66
X	20	E	E	X	300.0		1800.0		0.0		601%	1800	6.01	8.76	9.80	11.85	1800	6.00	8.77	9.82	11.90
X	20	E	E	X	180.0		1800.0		0.0		1001%	1801	10.01	13.66	14.94	17.56	1801	10.00	13.69	14.97	17.64
X	20	E	E	X	135.0		1800.0		0.0		1334%	1818	13.46	17.83	19.55	23.45	1817	13.46	17.85	19.59	23.56
X	30	E	E	X	200.0		1800.0		0.0		901%	1800	9.01	12.46	13.70	16.11	1800	9.00	12.48	13.74	16.19
X	30	E	E	X	150.0		1800.0		0.0		1202%	1802	12.02	16.03	17.49	20.21	1800	12.00	16.03	17.51	20.29
X	30	E	E	X	135.0		1800.0		0.0		1334%	1801	13.34	17.64	19.10	21.97	1800	13.33	17.64	19.12	22.01

Table 25: Verification of simulation model with normal distributions

Offloading simulation - Verification of simulation model - Normal																					
	No of	Distributions			Parameters						Traffic	Simulation					Queuing theory				
X	Chan-nels	Arrival Distr	Service Distr	Moveup Distr	Avg Arrival	Std Dev Arrival	Avg Service	Std Dev Service	Avg Moveup	Std Dev Moveup	Ratio (%)	Avg Delay	Avg Queue	90% Queue	95% Queue	99% Queue	Avg Delay	Avg Queue	90% Queue	95% Queue	99% Queue
X	1	N	N	X	6000.0	6000.0	1800.0	1800.0	0.0		30%	3771	0.63	1.74	2.77	5.32	2571	0.43	0.95	1.63	2.90
X	1	N	N	X	3600.0	3600.0	1800.0	1800.0	0.0		50%	4371	1.21	3.01	4.41	7.59	3600	1.00	2.40	3.40	5.72
X	1	N	N	X	2250.0	2250.0	1800.0	1800.0	0.0		80%	9310	4.13	9.68	12.87	19.92	9000	4.00	9.34	12.45	19.66
X	2	N	N	X	3000.0	3000.0	1800.0	1800.0	0.0		60%	2305	0.77	1.69	2.77	5.25	1978	0.66	1.40	1.71	3.28
X	2	N	N	X	1800.0	1800.0	1800.0	1800.0	0.0		100%	2689	1.49	3.35	4.68	7.89	2400	1.33	2.80	3.80	6.08
X	2	N	N	X	1125.0	1125.0	1800.0	1800.0	0.0		160%	5161	4.59	10.13	13.23	20.21	5000	4.44	9.81	12.91	20.12
X	5	N	N	X	1200.0	1200.0	1800.0	1800.0	0.0		150%	1851	1.54	2.77	3.55	5.98	1810	1.51	2.74	3.36	4.72
X	5	N	N	X	720.0	720.0	1800.0	1800.0	0.0		250%	1965	2.73	4.65	6.19	9.47	1894	2.63	4.47	5.47	7.77
X	5	N	N	X	450.0	450.0	1800.0	1800.0	0.0		399%	2846	6.31	12.03	15.10	21.93	2797	6.22	11.70	14.80	21.99
X	10	N	N	X	600.0	600.0	1800.0	1800.0	0.0		300%	1805	3.01	4.85	5.78	7.88	1800	3.00	4.84	5.67	7.24
X	10	N	N	X	360.0	360.0	1800.0	1800.0	0.0		501%	1833	5.09	7.63	8.61	12.56	1813	5.04	7.57	8.62	10.89
X	10	N	N	X	225.0	225.0	1800.0	1800.0	0.0		800%	2211	9.82	15.96	19.34	26.97	2168	9.64	15.34	18.45	25.66
X	20	N	N	X	300.0	300.0	1800.0	1800.0	0.0		601%	1802	6.01	8.73	9.91	12.53	1800	6.00	8.77	9.82	11.90
X	20	N	N	X	180.0	180.0	1800.0	1800.0	0.0		1002%	1806	10.03	13.63	14.98	18.11	1801	10.00	13.69	14.97	17.64
X	20	N	N	X	135.0	135.0	1800.0	1800.0	0.0								1817	13.46	17.85	19.59	23.56
X	30	N	N	X	200.0	200.0	1800.0	1800.0	0.0		901%	1802	9.01	12.40	13.74	16.73	1800	9.00	12.48	13.74	16.19
X	30	N	N	X	150.0	150.0	1800.0	1800.0	0.0		1201%	1801	12.01	15.91	17.45	20.53	1800	12.00	16.03	17.51	20.29
X	30	N	N	X	135.0	135.0	1800.0	1800.0	0.0								1800	13.33	17.64	19.12	22.01

Table 24: Verification of simulation model with log normal distributions

Offloading simulation - Verification of simulation model - Lognormal												Simulation										
	No of	Distributions			Parameters						Traffic	Simulation					Queuing theory					
X	Chan-nels	Arrival Distr	Service Distr	Moveup Distr	Avg Arrival	Std Dev Arrival	Avg Service	Std Dev Service	Avg Moveup	Std Dev Moveup	Ratio (%)	Avg Delay	Avg Queue	90% Queue	95% Queue	99% Queue	Avg Delay	Avg Queue	90% Queue	95% Queue	99% Queue
X	1	L	L	X	6000.0	6000.0	1800.0	1800.0	0.0		30%	2310	0.38	0.84	1.24	2.52	2571	0.43	0.95	1.63	2.90
X	1	L	L	X	3600.0	3600.0	1800.0	1800.0	0.0		50%	3286	0.91	1.97	2.95	5.56	3600	1.00	2.40	3.40	5.72
X	1	L	L	X	2250.0	2250.0	1800.0	1800.0	0.0		80%	8708	3.87	9.12	12.36	20.38	9000	4.00	9.34	12.45	19.66
X	2	L	L	X	3000.0	3000.0	1800.0	1800.0	0.0		60%	1901	0.63	1.23	1.74	2.76	1978	0.66	1.40	1.71	3.28
X	2	L	L	X	1800.0	1800.0	1800.0	1800.0	0.0		100%	2264	1.26	2.48	3.32	5.57	2400	1.33	2.80	3.80	6.08
X	2	L	L	X	1125.0	1125.0	1800.0	1800.0	0.0		160%	4743	4.21	9.26	12.48	20.16	5000	4.44	9.81	12.91	20.12
X	5	L	L	X	1200.0	1200.0	1800.0	1800.0	0.0		150%	1808	1.50	2.66	3.11	4.22	1810	1.51	2.74	3.36	4.72
X	5	L	L	X	720.0	720.0	1800.0	1800.0	0.0		250%	1863	2.58	4.22	4.96	6.87	1894	2.63	4.47	5.47	7.77
X	5	L	L	X	450.0	450.0	1800.0	1800.0	0.0		399%	2687	5.95	10.87	13.95	21.25	2797	6.22	11.70	14.80	21.99
X	10	L	L	X	600.0	600.0	1800.0	1800.0	0.0		300%	1804	3.00	4.76	5.50	6.85	1800	3.00	4.84	5.67	7.24
X	10	L	L	X	360.0	360.0	1800.0	1800.0	0.0		500%	1810	5.02	7.44	8.35	10.17	1813	5.04	7.57	8.62	10.89
X	10	L	L	X	225.0	225.0	1800.0	1800.0	0.0		799%	2112	9.36	14.39	17.07	23.74	2168	9.64	15.34	18.45	25.66
X	20	L	L	X	300.0	300.0	1800.0	1800.0	0.0		601%	1804	6.01	8.68	9.65	11.55	1800	6.00	8.77	9.82	11.90
X	20	L	L	X	180.0	180.0	1800.0	1800.0	0.0		1001%	1804	10.01	13.61	14.82	17.20	1801	10.00	13.69	14.97	17.64
X	20	L	L	X	135.0	135.0	1800.0	1800.0	0.0		1333%	1814	13.41	17.69	19.19	22.30	1817	13.46	17.85	19.59	23.56
X	30	L	L	X	200.0	200.0	1800.0	1800.0	0.0		901%	1804	9.01	12.39	13.56	15.79	1800	9.00	12.48	13.74	16.19
X	30	L	L	X	150.0	150.0	1800.0	1800.0	0.0		1201%	1804	12.01	15.95	17.32	19.84	1800	12.00	16.03	17.51	20.29
X	30	L	L	X	135.0	135.0	1800.0	1800.0	0.0		1334%	1804	13.34	17.56	18.94	21.65	1800	13.33	17.64	19.12	22.01