A parsimonious agent-based emergency call centre model

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Statement of Originality

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DEDICATION

Dedicated to our children and grandchildren

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Abstract

A parsimonious agent-based emergency call centre model

by Bruce Graham Lewis

This thesis presents an agent-based model of an emergency services call centre. The original contribution of this thesis is to demonstrate that agent-based modelling can be used to simulate the operation of an emergency services call centre. The thesis demonstrates that a simple calibrated parsimonious agent-based computer model of an emergency call centre is capable of simulating a real emergency call centre by directly emulating the interaction between the call queue and the customer service representatives who service the calls.

The model is parsimonious in that it looks at the interaction between inbound calls and servers with a manager and without modelling the call centre technology or other agents. It was designed to run at a simulated one second resolution and results are available at any time during or at the end of a simulation run. This level of resolution was not found in models reported in the literature.

The New South Wales Police Assistance Line in Australia (NSWPAL) was the first of its type in the world for the reporting of urgent and non-urgent crimes and incidents, and is used as a case study in this thesis.

The thesis presents the first detailed research analysis of police emergency inbound call queues and the first detailed research analysis of the NSWPAL emergency and non-emergency queue data over a four year period is presented. The model's servers' parameters were calibrated against the NSWPAL data.

A number of experiments demonstrated the model's utility including showing differences and anomalies in the methods used to calculate service level, the impact of talk time on performance, the differences in call allocation methods, the impact of unexpected exogenous events, the use of historical data to examine past performance and the differences between the thesis and Erlang C models.

PUBLICATIONS FROM THIS RESEARCH

The following were published in conference proceedings and journal publications:

- Lewis, B., Herbert, R. and Chivers, W. (2010), ‘Modelling Service Levels in a Call Centre With an Agent-based Model, *World Review of Science, Technology and Sustainable Development* 7(1), 212.

- Lewis, B. G. and Herbert, R. D. (2009), Simulating the Call Streams to an Emergency Services Call Centre, in ‘The 6th International Conference on Information Technology and Applications, International Conference on Information Technology and Applications, pp. 259264.

- Lewis, B. G., Herbert, R. D. and Chivers, W. J. (2008), Modelling Service Levels in a Call Centre with an Agent-Based Model, in ‘Proceedings of the 5th International Conference on Information Technology and Applications, IEEE, pp. 426430.

- Lewis, B. G., Herbert, R. D., Summons, P. F. and Chivers, W. J. (2007), Agent- based Simulation of a Multi-queue Emergency Services Call Centre to Evaluate Resource Allocation, in L. Oxley and D. Kulasiri, eds, ‘MODSIM 2007, International Congress on Modelling and Simulation., Modelling and Simulation Society of Australia and New Zealand, Modelling and Simulation Society of Australia and New Zealand, `http://www.mssanz.org.au/MODSIM07/authorsL-M.htm`, pp. 11 17.

- Lewis, B. (2006), The Application of Computer-Based Modelling to the Management of Multiple Queues in an Emergency Services Call Centre, in ‘Proceedings of the Research Higher Degree Students Congress 2006, School of Design, Communication & Information Technology, University of Newcastle, Callaghan, Australia, pp. 3237.

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GLOSSARY

131444	The NSWPAL telephone number customers call for non-urgent matters.
ABM	Agent-Based Model.
ACW	After Call Work. This is also known as wrap-up time (Koole, 2007). It is the additional time an agent spends on a call after the call with the customer has ended.
AHT	Average Handle Time. It consists of the call talk time and the ACW.
ASA	Average Speed of Answer.
AWT	Acceptable Wait Time (Koole, 2007, Essafi and Bolch, 2005). The time within which a business or organisation would like all of its telephone calls to be answered[1].
CSR	Customer Service Representative.
CTA	Call Taking Agent. This term is used in the program code to distinguish the model agents from the human CSRs.
CTI	Computer-Telephony Integration.
ESO	Emergency Services Organisalion.
GUI	Graphical User Interface.
IBM	Individual-Based Model.

[1] Based on the researcher's experience in the call centre industry

NSWPF	New South Wales Police Force.
NSWPAL	New South Wales Police Assistance Line.
OOD	Object-Oriented Design.
OOP	Object-Oriented Programming.
Service level	The percentage of calls a business or organisation deems acceptable to be answered within the AWT. Although there is no standard for this, 20% is seen as representative for non-emergency call centres and 10% for emergency call centres[2].
TSF	Telephone Service Factor. See Service level above.
Triple Zero (000)	The Australia-wide emergency telephone number for Police, Ambulance or Fire Brigades.

[2] Based on the researcher's experience in the call centre industry

Chapter 1

INTRODUCTION

1.1 Introduction

The emergency services call centre is an integral and crucial component of our society. It is a point of contact for those in the community seeking assistance and its primary role is to take accurate information from the community to facilitate the despatch of emergency services vehicles and personnel. Emergency call centres have highly trained and skilled staff who work to stringent performance measures both at the individual and call centre levels.

The balance of available resources against expected or unexpected inbound call volume while maintaining the required queue performance underpins this research.

This thesis demonstrates that a simple agent-based computer model can be used to simulate the interaction between inbound calls and Call Taking Agents (CTAs) with a manager and without modelling the call centre technology or other ancillary agents.

1.2 Problem definition

While cost is an important factor in effectively managing an emergency call centre, it is the risk to the community that needs to be minimised. This requires efficacious staffing and management of the call queues. Goals of this research are to examine different call queue management techniques for future and past times or for specific events and to determine the impact of agent parameters on performance.

1.2.1 The research questions

The primary research question is:

Can a simple agent-based computer model be used to emulate the emergent performance of an emergency call centre by simulating the interaction of the inbound calls and servers?

Other questions arising are:

- What are the effects of agent parameters on call centre performance?
- Can call centre performance be improved by using different call allocation methods?
- How will the model respond to a sudden increase in calls?
- How do results from the model compare with the Erlang C model?
- What is the effect on performance of the different methods of determining the service level metric?
- Can the model be used to asses call centre performance when using historical data?

1.3 Contributions of this thesis

The original contribution of this thesis is to demonstrate that agent-based modelling can be used to simulate the operation of an emergency services call centre. This thesis also makes the following original contributions to the call centre industry:

- this thesis demonstrates that a simple calibrated parsimonious agent-based computer model of an emergency call centre is capable of simulating a real emergency call centre by directly emulating the interaction between the call queue and the CTAs,
- this thesis presents the first detailed research analysis of police emergency inbound call queues,
- specifically, this thesis presents the first detailed research analysis of the NSW-PAL emergency and non-emergency queue data over a four year period and
- simulation results are available at any time during or at the end of a simulation run. This level of resolution was not found in models reported in the literature.

1.4 Summary of findings

The primary outcome from this research is that a simple agent-based model can be use to simulate the holistic behaviour of an emergency call centre without the complexity of mathematical equations. Other findings from the research are summarised here:

- *Research on emergency call centres*: Emergency services call centres are a niche facility in the call centre industry having stricter operating parameters than many of their commercial counterparts. Although there was general acknowledgement of them in the literature there was a paucity that dealt specifically with emergency call centres and their modelling.

  The existing models are mainly mathematical and in the few instances where agent-based modelling was used, it was to model the tactical response of a number of emergency disciplines and included the call centre spatial and environmental aspects.
- *Use of agent-based modelling*: The use of a parsimonious agent-based computer

model to simulate the performance of an emergency call centre has not been reported in the literature.

In this thesis it was demonstrated that an agent-based model consisting of a few agent classes and simple timing loops can be used instead of a complex mathematical model. Such a model necessarily includes the contribution of the individual agents in achieving an holistic outcome.

While the focus of this thesis has been on the emergency call centre, the model is capable of being used more generally.

- *Simulation of an emergency call centre*: By undertaking a series of experiments that dealt with server parameters and inbound call volumes the agent-based model (ABM) described here was able to simulate the holistic performance of an emergency call centre.
- *The impact of talk time on service level*: It was found that the service level was dependent on talk time. This can be extrapolated to the overall call handle time which is the sum of handle time and after call work time.
- *Calculating service level*: It was found that the method of calculating service level is open to question, there being a number of formulae and no apparent industry standard. It was also found that there is no standard time frame over which service level is calculated, the methods of calculating service level do not include a time parameter and the number of calls waiting to be answered are not a consideration.
- *Inclusion of abandoned calls in service level calculations*: Use of the model confirmed that calculating service level without including abandoned calls gave a more optimistic results than if it was included. Because there are a number of ways that the service level of a call centre can be calculated the question as to whether or not abandoned calls should be included is open and up to the interpretation of the individual call centre managers.

- *Response to a sudden increase in calls*: The model demonstrated a slow recovery time constant after a sudden increase in calls. Over a set simulation time frame, an increase of 41% in the number of servers alone was insufficient to bring the service level back to target. However over the same period this increase in servers together with a 10% decrease in the call handle time was able to achieve this. This depended on the method of calculating service level and this demonstrated and confirmed that managers can only have a small impact on call centre performance in the short term.
- *Anomaly in calculating service level*: With the exception of the Erlang C model, the different methods of calculating service level identified in this thesis produced an indeterminate result at the start of the performance measurement period until the first call was taken by a server.
- *The impact on service level of different call allocation methods*: The model was insensitive to the server call allocation method, when homogeneous calls and servers were used. This was due to the deterministic nature of the model.
- *Analysis of queue data*: From the analysis of New South Wales Police Assistance Line (NSWPAL) queue data over a four year period it was found that the urgent and non-urgent queues had different call profile signatures. The literature did not present daily call profiles for police-related emergency call queues and no detailed analysis of the emergency inbound calls to police facility was found.
- *Statistical comparison*: A statistical comparison of call handle times from the model against NSWPAL queue data showed agreement. This was important in providing a basis for the calibration of the model.
- *Model timing accuracy*: A large number of call states and server states facilitated accurate timing for the model. The intricacies of the timing relationships

between the manager agent, the call agents and the CTAs were found to be very important.

- *Comparison with the Erlang C model*: By comparing the method of calculation of service level in the thesis model with the Erlang C model it was found that in contrast to the latter the thesis model is not stationary and the contribution of the individual call takers is taken into account over the simulation period.
- *Using historical data to predict performance*: By using historical summary data with the model it was possible to simulate the expected average performance of the call centre. Such a facility would allow call centre managers to undertake "what if?" testing with different agent and call parameters before committing staff schedules.
- *Number of CTA states*: A finding of this work was the need for more agent states than originally planned. These gave greater control of the call management process throughout the various stages of processing the calls.
- *Using Erlang C model to calculate the number of CTAs*: It was found that the Erlang C model can be used to estimate the number of CTAs for the thesis model. However, due to the differences in results between the thesis and Erlang C models the latter only provides a good place to start in determining staffing.
- *The effect of talk time on service level*: As the talk time increased, the service level was found to decrease given that other parameters remained constant. The outcome of this experiment is for call centre managers to ensure that CSRs are trained and empowered to service their calls in the least time possible while providing good customer service.

1.5 The model

To answer the research questions an agent-based computer model was developed, the conceptual design of which is shown in Figure 1.1 and highlights the parsimonious nature of the model.

The model objectives are to:

- construct a calibrated model that operates in simulated real time at one second resolution,
- analyse one of two independent customer queues at a time for urgent or non-urgent calls,
- focus on the interaction between the queues and CTAs,
- use the service level as the main performance metric, and
- identify subsequent further work from the research.

The model assumptions are:

- the model operates where one time step of the program corresponds to one second of real time,
- calls enter at a constant rate which is determined by the user,
- there its no blocking of inbound calls due to insufficient lines,
- there is a single manager,
- there are multiple homogeneous CTAs which have different properties for each queue,
- there are independent urgent and non-urgent call types with different homogeneous properties in the respective groups,
- the technical systems that may precede or follow the servers are not included in the model,
- the model does not include the call centre physical environment such as background noise,

- calls are not put on hold, and
- calls remain in their queue until answered or until they abandon and do not flow to other systems such as voice mail.

The model features are:

- two independent queues for urgent and non-urgent calls,
- a graphical interface to set the parameters of the simulation runs and keep track of these,
- inbound calls from user-specified or historical data,
- a shock generator that increases the call volume by a user-specified amount, time and duration,
- the ability to add additional agents at a specific time to service an additional call load,
- user-specified call and CTA parameters,
- different methods to allocate calls to the CTAs,
- comprehensive performance reports at user-specified steps throughout the simulation and at the end,
- comprehensive graphical results the composition of which are determined by the user,
- analysis of the performance in any time frame with the ability to track the progress of a simulation in fine detail, and
- tabular results formatted to be included in a LaTeX document.

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The model centres on the CTA processes of servicing the calls from a call queue. A detailed description of the model can be found in Chapter 4.

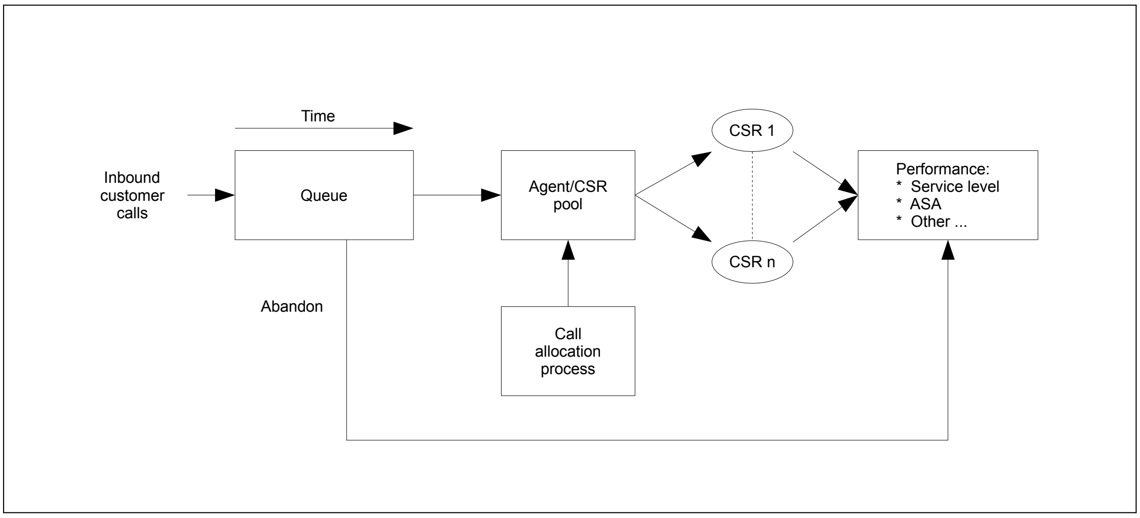

Figure 1.1: The conceptual design of the agent-based model.

1.6 *Case study - NSW Police Assistance Line*

The researcher has had ten years experience in the call centre industry in the position of Operations and Business Development Manager at the Police Assistance Line in New South Wales, Australia. In this position, the researcher was responsible for the development and management of business plans and business cases, high level performance analysis and the management of the technical support section. There were times when the researcher transferred to the position of Call Centre Manager to manage the day-to-day operations of the larger of the two call centres. In this thesis, NSWPAL is used as a case study where four years of data for two of the business queues were used as a basis for calibrating the model and examining its performance under different queue management techniques.

The New South Wales Police Force is an Emergency Services Organisation (ESO) in the state of New South Wales, Australia. The New South Wales Police Assistance Line (NSWPAL) is an emergency services multi-site, multi-queue, multi-server, inbound call centre. It has been in existence in NSW statewide operation since December 1999. It is a 24 hour inbound telephone call centre available to police and the community. NSWPAL was the first of its type in the world and is a niche facility in the call centre industry, being used for the reporting of both urgent and non-urgent calls and incidents, for providing police-related information to the community and for providing an intelligence source for the NSW Police Force.

NSWPAL currently operates a number of business streams and caters for planned and unplanned emergency and special operations. The business streams include Triple Zero (000), Crime Stoppers, 131444, Customer Assistance Unit and the police telephone switchboard. NSWPAL also provides call centre services for special operations and at times other NSW State Government agencies. In Australia, Triple Zero (000) is the number dialled when people require urgent assistance for an emergency service organisation. This is analogous to emergency numbers such as 112, 911 and 999 used in other parts of the world. 131444 is an Australia-wide telephone number allocated to police jurisdictions call centres across Australia for the reporting of crime. Each jurisdiction operates the service differently. In the state of New South Wales, 131444 is a statewide service. This research in this thesis looks only at the Triple Zero (000) and 131444 queues.

In the financial year 2008-2009, NSWPAL took a total of 1,642,929 calls across all business queues with 519,458 calls in the 131444 queue and 865,306 calls in the Triple Zero (000) queue (NSW Police Force Public Affairs Branch, 2009).

NSWPAL is configured as two geographically diverse call centres operating as a single virtual call centre by virtue of its technology base. It uses modern information technology and systems throughout all of its businesses. A computer-telephony integration (CTI) system monitors and manages the incoming calls and ensures that all calls are routed to the suitably trained agents. The same system maintains a comprehensive database that is used to show the centre's performance in real time and as a basis for the preparation of a variety of management reports. A proprietary workforce management system is used to forecast the incoming call queue volumes and to prepare schedules for staff in accordance with their needs and NSWPAL's business needs to meet the forecast demand.

NSWPAL's performance is primarily measured in terms of its service level, being the percentage of calls answered in a specified time with each queue having its own metric. Daily performance for the 131444 non-urgent queue is published on the home page of the NSW Police website at http://www.police.nsw.gov.au/. This overall performance is directly related to the performance on the staff including the Customer Service Representatives (CSRs) who take the calls and the team leaders who continually manage the queues. For an emergency services call centre prompt responses to the callers are essential and NSWPAL has highly trained and skilled CSRs to handle the calls.

It will be shown in this thesis that while the inbound call queue traffic is predictable emergency call centres operate in an environment of uncertainty with respect to unanticipated events that occur in the community and are expected to meet community expectations in the provision of immediate assistance.

Support and approval to undertake the research using NSWPAL data was given by the NSW Police Force. The data used in this thesis are numerical and de-identified and ethics approval for the research was given by the University of Newcastle, Australia, Human Research Ethics Committee (Reference No: H-532-0707).

1.7 NSWPAL call management business model

The NSWPAL call management business model can be viewed as two distinct phases being preliminary processes and real time processes. These are shown in Figure 1.2.

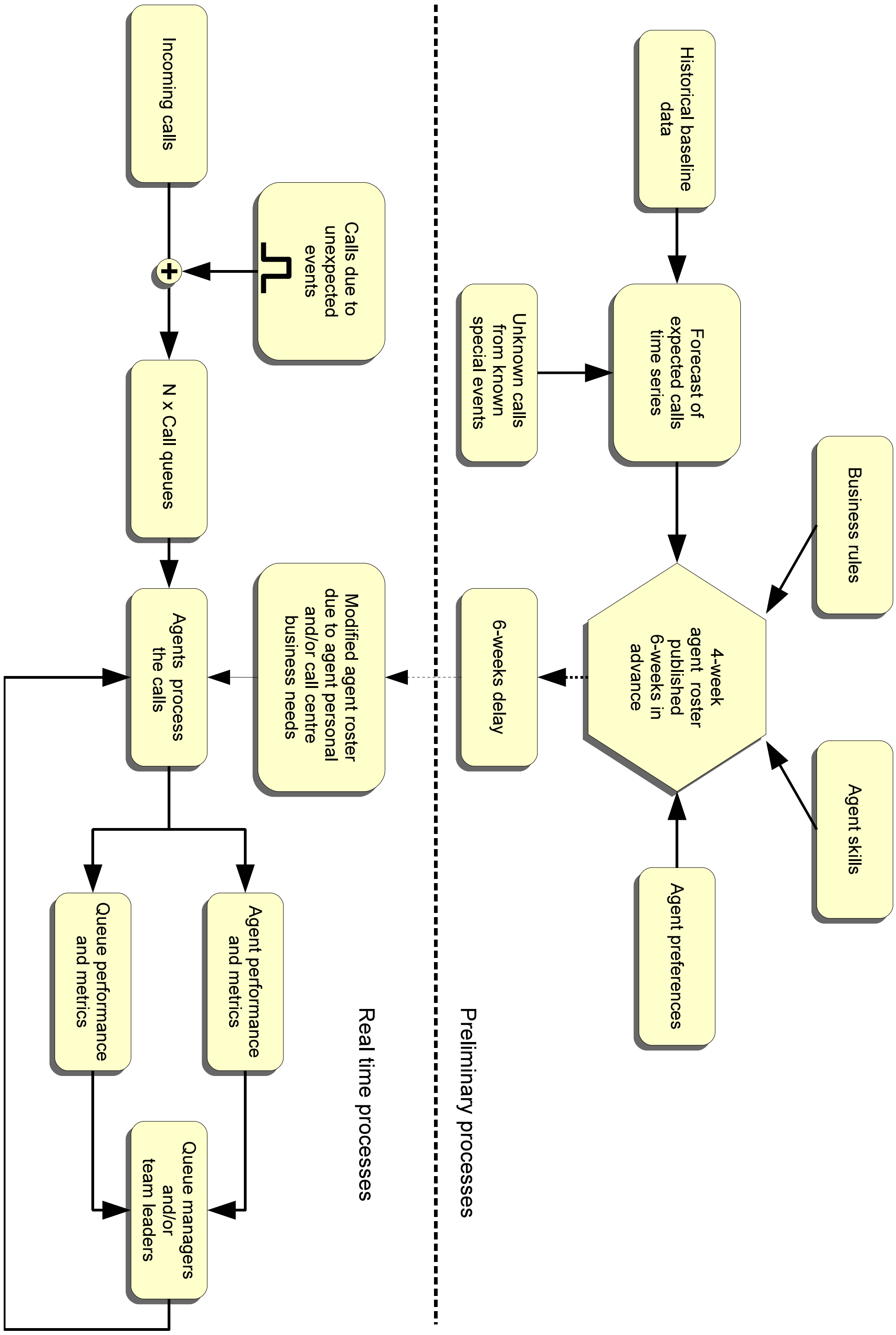

Figure 1.2: NSWPAL call management business model.

The preliminary processes involve the forecasting and scheduling processes. At NSWPAL, the CSR four-weekly rosters are prepared six-weeks in advance. These are based on the forecast call volume, service level, the CSR preferences and the NSWPAL business rules. However, in the six weeks before the roster starts events occur in the CSRs' lives that necessitate changes to their roster. Each of the queues has a different service level target. For the urgent queue the target is to answer 90% of calls within 10 seconds while the non-urgent is 80% within 27 seconds. Friday nights, early Saturday mornings, Saturday nights and public holidays can be busy periods for either or both queues.

The real time processes involve the management of the call queues in accordance with agreed performance and business rules. However, on any particular day, two things occur that impact on the centres ability to meet its service level and may involve last minute changes to the CSR schedules. First, CSRs may not come to work due to illness, other NSW Police Force business, unexpected leave, or other personal reasons. The second is unexpected exogenous events such as a public disturbance or a public safety event. One particular unexpected event in July 2007, for example, caused a drop in performance of the urgent queue. This event is discussed in Chapter 3.

1.8 Call centre performance

Black (1998) cited in Gilmore (2001)) noted that a call centre's efficiency is critical to an organisation's image. Like all businesses, NSWPAL is resource limited.

Call centre performance is judged by a variety of metrics. Of these, the most common presented in the literature are the Average Speed of Answer (ASA), Service Level or Telephone Service factor (TSF) being the percentage of calls answered within a specified time and percentage of abandoned calls (Duder and Rosenwein, 2001, Mehrotra and Fama, 2003), (Gans et al., 2003 (cited in Robbins et al. (2006))). Pichitlamken et al. (2003) note that since call centres aggregate their measurement into intervals of, say, 30 minutes, lack of call by call information complicates analysis of the data since standard parameter estimation techniques do not usually apply. At NSWPAL, the granularity is 15 minutes and this is used for forecasting the call rate, scheduling the CSRs and reporting.

One of the parameters that impacts the performance of an inbound call centre is the call arrival rate. Betts et al. (2000) note that call centres have seasonal demand patterns and many experience short term spikes in demand, for example due to weather conditions, with capacity management being a trade-off between operator boredom and high service levels.

In previous research undertaken by the researcher (Lewis, 2003, Lewis et al., 2003) of the NSWPAL non-urgent inbound call queue, it was shown that there were strong daily and weekly patterns together with unexpected spikes in the incoming call rate. This research showed that Fourier Analysis could be used to forecast the inbound call stream to an emergency call centre. For this thesis a similar analysis of the data was undertaken with new data for the Triple Zero (000) and 131444 queues over a four year period with similar results. These are discussed in Chapter 3.

1.9 Thesis structure

Chapter 2 contains the literature review and confirms the basis for the research. It explains the purpose of a call centre along with their advantages and disadvantages. In this chapter previous research into emergency call centres and industry literature are critically examined and discussed. In particular, call centre staff costs are identified as a significant portion of their operating costs. Call centre performance measurement is examined, the different ways of measuring service level are discussed and a critical evaluation of the use of modelling and simulation as a research tool is undertaken. The chapter identifies that agent-based modelling is suited to this research and that this method has not previously been used to model the relationship between call queues and CSRs in emergency call centres.

In Chapter 3 the research approach is explained along with the collection, preparation and analysis of the NSWPAL data used in this thesis. These data cover a four year period from January 2005 to December 2008 inclusive for the NSWPAL urgent and non-urgent queues and had not previously been analysed to the level of detail in this thesis. It is shown that the daily summary data patterns for both the urgent and non-urgent queues were highly predictable. The summary statistics for this analysis are presented for the Triple Zero (000) and 131444 queues in Appendix A and the results are contained in Chapter 3. Unexpected exogenous events can have a significant impact on a call centre's performance and in particular the service level metric. One such event was discussed an analysed. The results are shown graphically in Chapter 3 and the numerical results are presented in Appendix B. This event showed the effect of an unexpected situation in the community on both queues and was used in later chapters to examine the performance of the model.

Chapter 4 explains the path taken by the researcher to develop the model and explains the facilities and processes within the model. First, a successful prototype was built as a single program. This was followed by the final model that was built as a series of program modules. This allowed a high level of flexibility in implementing different strategies. Before settling on the composition of the final model a detailed comparison of the prototype model and final model performance was undertaken. In particular the timing sequences were compared and the programs' parameters were adjusted to ensure identical results. An finding of this work was the need for more agent states than originally planned. These gave greater control of the call management process throughout the various stages.

In preference to changing parameters within program code a Graphical User Interface (GUI) was written. The GUI made it easy to make small changes to the input values and monitor the changes in the results when the model was run. The chapter contains a detailed explanation of this and the model's components.

An important aspect of the model was its calibration against NSWPAL data. Chapter 5 discusses the calibration of the model's call handle time and abandon time parameters, and a means for determining the number of CTAs. The chapter explains the process undertaken to calibrate the thesis model against the NSWPAL data and demonstrates that the model developed here was a good approximation of the NSWPAL call centre. Another aspect of this chapter was that the thesis model and the Erlang C model were compared with respect to the estimation of the number of CTAs required for similar model inputs. The two models produced different results due to differences in their inherent natures with one of the main differences being that the thesis model took the progress of time and the individual call takers contribution into account and the Erlang C model did not. The NSWPAL data used in the parameter determination and calibration is shown in Appendix B.

Chapter 6 introduces a collection of experiments that demonstrate the capabilities of the model. Two of the experiments show anomalies associated with the common methods of calculating service level. Furthermore, one of the topics debated in the literature was whether or not abandoned calls should be included in the calculation of service level. The differences between the methods of calculation are demonstrated in this chapter and in other chapters of this thesis.

The model was subjected to a sudden increase in calls which resulted in the service level dropping quickly. To manage the situation, additional call taking resources were added. The number and timing of these was determined by running the model with different input values and analysing the results. In all cases, it was found that the model had a long recovery time constant and within the bounds of the parameters for this experiment it was not possible to return the service level to the target value.

The experiment was extended to include the effect of call handle time. It was found that a modest decrease of 10% was sufficient to bring the service level back to the target level. However, this still occurred over a long time frame and was dependent on the service level calculation method. The reason for this was because the CTAs were homogeneous and this resulted in the outcome being determinate.

Four different methods of allocating calls to the call taking agents were assessed and it was found that the model was insensitive to changes in the call allocation method. However when the calls were allocated randomly the results improved with the level of improvement again dependent on the service level calculation method.

Another experiment demonstrated that historical summary statistics could be used as a basis for the prediction of call centre performance.

In the last experiment, it was shown that when comparing the performance of the thesis and Erlang C models, the thesis model demonstrated that the contribution of the individual call takers were taken into account over the simulation period.

These experiments demonstrated that the model was capable of providing results that emulated the performance of an emergency call centre.

Chapter 7 contains the conclusions from this research and identifies future work that could extend the operation, performance and utility of the model.

At the end of the thesis there are four appendices. The first contains the four year summary analysis of NSWPAL data for the Triple Zero (000) emergency queue and the 131444 non-emergency queue. These data cover 15 minute steps for each day of the week and can be used as input data for the model. The second contains emergency and non-emergency queue data for an exogenous event that adversely affected the performance of the NSWPAL emergency queue, the third appendix lists the resources used for this research and thesis and the final appendix describes the media that contains the program code.

1.10 Presentation of the research

This research has been presented at local and international conferences including:

- the University of Newcastle, Australia Research Higher Degree Students Congress (Lewis, 2006),
- the Modelling and Simulation Society of Australia & New Zealand International Congress on Modelling and Simulation MODSIM07 (Lewis et al., 2007),
- the 5th International Conference on Information Technology and Applications (ICITA 2008) (Lewis et al., 2008) and
- the 6th International Conference on Information Technology and Applications (ICITA 2009) (Lewis and Herbert, 2009). This conference paper was published in the World Review of Science, Technology and Sustainable Development Journal in 2010 (Lewis et al., 2010).

In the next chapter, a review of the literature will highlight a paucity of detailed information about emergency call centres and that the use of a parsimonious agent-based computer model to simulate the performance of an emergency call centre has not been reported.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews literature relating to call centres and focussing on those areas specific to the creation of the agent-based model. In particular, the use of call centres is examined and the differences between those used by emergency services and other sectors of the industry highlighted. Next, key performance measures are examined including the calculation of service level and the impact of customers abandoning a queue while waiting for service.

Finally, the different methods used to model call centres are discussed and the reason for the selection of the agent-based model is explained. Excluded from the review are the areas of forecasting and an explanation of the technical systems used by call centres as these are not part of the model. Should the reader require information on these, then there are very good explanations of these systems in the academic literature (Koole and Mandelbaum, 2002, Gans et al., 2003) and the industry literature (Genesys Telecommunications Laboratories, Inc., 2009, Salmat Speech Solutions, 2010) with the latter having a very good glossary.

Much of the call centre literature is in commercial or business terms (Mehrotra and Fama, 2003, Omari and Al-Zubaidy, 2005, Gilmore, 2001). Moreover, the literature on call centre research was found to come from two different directions; the peer reviewed academic sources and from the non-peer reviewed papers and books written by practitioners. In examining this literature, it was found that there was little specifically related to emergency services. The researcher has addressed this by presenting research associated with this thesis at international conferences to expand the knowledge on these facilities. These include:

- the University of Newcastle, Australia Research Higher Degree Students Congress (Lewis, 2006),
- the Modelling and Simulation Society of Australia & New Zealand International Congress on Modelling and Simulation, MODSIM07 (Lewis et al., 2007),
- the 5th International Conference on Information Technology and Applications (ICITA 2008) (Lewis et al., 2008) and
- the 6th International Conference on Information Technology and Applications (ICITA 2009) (Lewis and Herbert, 2009).

The ICITA 2009 conference paper was published in the World Review of Science, Technology and Sustainable Development journal in 2010 (Lewis et al., 2010).

2.2 The call centre

This section explains the role call centres, why they are of interest, their running costs, their advantages, their disadvantages and why emergency services call centres differ from commercial and other government facilities. It will be shown that because of its role in society, the emergency services call centre is a niche facility in the call centre industry.

2.2.1 What is a call centre?

First, the difference between a call centre and a contact centre needs to be explained. A call centre delivers its services by telephone and the contact centre is an extension of this with additional multimedia technology such as FAX, email and voice recognition systems (Koole and Mandelbaum, 2002, Mandelbaum and Zeltyn, 2007). The focus on the telephony definition is seen in Robbins et al. (2006), Gans et al. (2003), Omari and Al-Zubaidy (2005) and Gilmore (2001). Mehrotra and Fama (2003, p.135) see call centres as 'stochastic systems with multiple queues and multiple customer types.' The people or agents who answer and process the calls are referred to as Customer Service Representatives (CSRs) (Gans et al., 2003).

Anton (2000) identified the call centre as being the future customer access centre and later Gans et al. (2003) noted that call centres are a primary link between customers and service providers and that the industry is rapidly expanding.

The NSW Police Force saw this an as important opportunity to centralise the reporting of non-urgent crime and the release of police officers to front line duty by employing civilian personnel to take the calls. Following a proof of concept trial, the NSWPAL was introduced as a state-wide service from December 1999. In the ensuing years, new business streams including Crime Stoppers [1] and the Triple Zero (000) services were added. In 2006, it was estimated that the NSWPAL released around 200 police to frontline duty (Achterstraat, 2006). The NSWPAL was the first of its type in the world.

Mehrotra and Fama (2003) see a number of reasons as to why call centres are interesting including:

- the worldwide size of the industry,
- the operational and mathematical complexity,
- their multi-queue nature, the inbound calls arrival times randomness,
- the random call durations,

[1] See: http://www.crimestoppers.com.au/cs/home.jsp

- routing technologies complexity, and
- the CSR skill sets differences to handle a variety of call types.

For these reasons they state that without effective modelling, decision makers have difficulty understanding the system dynamics. They explain the challenges faced by call centre managers include balancing the main areas of service quality, the costs and employee satisfaction. These, they say, lead to important issues for which decision support models are of benefit:

- the number of agents,
- agent skill sets,
- how agents should be scheduled including shifts, breaks, training, meetings and other activities,
- call types, quantities and when they will arrive,
- inbound calls response time,
- agent multiple queue training, and
- call centre performance against forecast, schedule and routing design.

2.2.2 Call centre advantages and disadvantages

Bennington et al. (2000) explain that the advantages to customers who deal with a call centre include greater convenience due to the need not to travel to the company offices resulting in a reduced cost to make the call, quick service once connected due to newer technologies and, in some cases, the ability to communicate in the language of their choice. They state that advantages to the organisations that have a call centre include the ability to service many customers at the one time, improved call streaming with customers making selections, and less management costs due to reduced or no office space for customers.

The disadvantages for customers include lower customer satisfaction than face-to-face contact, reliance on technology since customers expect it to always work (Bennington et al., 2000), frustration in long wait times in the belief that call centres provide timely service and, not being comfortable with telephone transactions (Crome, 1998). From the management viewpoint disadvantages include managing customer perceptions where the customer has no visual queues, lack of face-to-face contact, management of customers who would rather deal with a person directly (Bennington et al., 2000) and the difficulty in building 'effective, personalised customer relationships' with no direct personal contact (Crome, 1998, p.137).

Experience with the NSWPAL highlights other advantages including the use of common technical systems, common technical infrastructure, common management systems, common business rules and in-house support services located with the call centre business unit. These translate to reduced costs for maintenance, training and performance management.

2.2.3 Call centre costs

There are a number different costs associated with a call centre and these costs can be divided into tangible and intangible costs. The tangible costs include recruiting, training and paying staff, telecommunications, technical systems, building related costs, utilities and office supplies. The intangible costs include political fallout, reputation and unfavourable media reporting.

Much of the driving force associated with call centre management and research is centred around improving efficiencies due to the high cost of the call centre labour force (Duder and Rosenwein, 2001, Brown et al., 2005). In particular, Duder and Rosenwein (2001) identify that the cost of providing trained operators exceeds half of the operational costs of a call centre. Brown et al. (2005) identify this as being in the order of 70% or more of the a call centre's total running cost and the National Audit Office (2002, p.5) found that:

> 'An independent global benchmarking study[2] indicated that for an average call centre 66 per cent of costs were on staffing. For departmental call centres the equivalent figure was 77 per cent and for those outsourced 56 per cent.'

One of the major drivers for call centre efficiency is cost and much of the research around call centres is on finding the optimum way to staff them (Erdem and Gedikoglu, 2006). Hughes (1995, p.87) notes that since 'incoming call centers are often viewed as cost rather than profit centers accurate staffing is a primary concern' and that staffing to meet service levels with tight cost constraints is a challenge. Chassioti and Worthington (2004, p.1352) identify that:

> 'Call centres have significant general management challenges, in human resources (recruitment, absenteeism, emotional support, burnout, call monitoring policies), MIS (multiuser multisite databases, customer tracking, system integration), training, and quality.'

The researcher notes that to this must be added training and quality management, both essential processes in call centres with each of these having a financial impost on the call centre.

In the emergency services arena, call centres are generally cost centres since the service they provide is borne by society without cost to the customer. There are other operational costs associated with an emergency service such as the cost to call in staff on overtime or to shorten meal breaks within the business rules to meet the service level required for urgent calls. Based on experience at the NSWPAL, one

[2] Merchants Global Contact Centre Benchmarking Report 2001.

of the challenges in managing an emergency service call centre is trading off cost against servicing the customers expectations whilst maintaining an expected service level. While cost is an important issue in the emergency services call centre, the main focus is on public and officer safety and so the goals are to gather accurate information and efficiently facilitate the provision of field resources.

2.2.4 The emergency call centre

There is little literature that deals explicitly with the emergency services segment of the call centre industry. An extensive review revealed that, other than Chen and Henderson (2001) and that produced by the author of this thesis, little was found that dealt specifically with emergency response call centres in any depth. The following were found to have some 'emergency' content:

- Antipov and Meade (2002) discuss forecasting and mention emergency services call centres and other similar facilities that provide assistance on demand.
- Atlason et al. (2004, p.333, p.337) present a method for minimising call centre staff costs. They 'assume that the service level cannot be easily computed, and instead is evaluated using simulation' and state that 'In an emergency call center, for example, it might be required that 90% of received calls should be answered within 10 seconds'.
- Avramidis and L'Ecuyer (2005) mention that call centres handle emergency services and that call centres costs account for about three-quarters of the labour cost.
- Bieger et al. (2009) discuss solutions to improve the performance of a Brazilian medical emergency call centre. Their approach is to observe processes, interview employees and other organisations and analyse questionnaires they had disseminated amongst different groups. They analysed inbound data af-

ter removing prank calls. Rockwell Software's Arena[3] application was used for their simulation. Their first outcome was to use posters, bumper stickers and a comic strip in local newspapers to deter prank calls from children. From the results of their simulation, the second outcome was to implement a simple scheduling system to reduce the medic's workload and increase operational efficiency.

- The work of Chen and Henderson (2001, p.175) focussed on determining staff levels in a Police Communications Centre in Auckland, New Zealand with priority customers. They noted the importance of considering random arrival rates and noted that historical data may 'in some cases, lead to considerable errors in performance estimates for a given staffing level.' Mathematical modelling is used to determine their outcomes.
- Dugdale et al. (2000) developed a tactical computer-based simulation of an emergency call centre using the 'SWARM' application[4]. The model has fire agents, health agents and physician agents. It also reflects the physical locations of the agents in the actual call centre and the environmental parameters such as noise are included. At the time of writing their paper, the model was 'in the early stages' (Dugdale et al., 2000, p,241) and the results were preliminary. Their experiments included moving agent locations and arranging different files for specialist information. A later article on the final outcome could not be found. However, Dugdale was the co-author of a similar paper in 2006 (Saoud et al., 2006) and in this case the Java Agent DEvelopment Framework (JADE)[5] was used to build a tactical model of a multi-disciplinary 'complex socio-technical collaborative complex system' (Saoud et al., 2006, p.1) for emergency situations.

[3] See http://www.arenasimulation.com/
[4] See http://www.swarm.org/index.php/Main_Page
[5] See http://jade.tilab.com/

- Forslund et al. (2004, p.290) studied the operator experience at a Swedish emergency dispatch centre using a 'phenomenological-hermeneutic approach'. The centre provides calls requiring ambulance, fire, police and 'other acute services'. The study identified the operator's job was challenging, complex and intricate and involved uncertainties, communications difficulties and insufficient external resources as some of the problems they encountered. It also stated that in decision making the operators needed to be flexible, compassionate, efficient and courageous. The outcome of the study was that the operators needed more guidance, education and feedback.
- Gans et al. (2003) mentioned that emergency services use call centres as a preferred means of contact with their customers. The paper gave an in-depth explanation of call centres, their processes and their management across all call centre types without differentiating the emergency services segment.
- Gunal et al. (2008) used the Micro Saint Sharp[6] modelling application to build an event based tactical model for 'a UK Police Force'.
- While the research by the National Audit Office (2002) dealt with the delivery of public service with call centres, it made no specific mention or provided data for the emergency services organisations.
- Koole and Mandelbaum (2002) provided information about call centre mathematical queueing models. There was no in-depth discussion about emergency call centres.
- Kozan and Mesken (2009, p.2602) built an event-based 'analytical based simulation model' with a commercial product called Extend V6 [7].
- Loper and Presnell (2005, p.895) presented a broad tactical agent-based model that simulates information flow between people in an emergency operations

[6] See http://www.alionscience.com/index.cfm?fuseaction=Products.viewpage&productid=35&pageid=113/

[7] See http://www.extendsim.com/sols_simoverview.html#discreteEvent

centre. The agents consisted of managers, technical systems, call takers, agencies, the outside world and action officers at various levels and locations. The model had agents that interacted dynamically and was used to evaluate the individual agent behaviour and 'the complex phenomena of the large-scale, complex socio-technical system'. They do not specifically model the interaction between the customer and agents.

- Ramaswami et al. (2005) examined the impact of inbound Internet traffic that caused dial-tone unavailability and find patentable solutions.
- Robbins et al. (2006) briefly referred to emergency dispatch as a call centre application.
- Wereschagin (2009) wrote a newspaper article that demonstrates the sudden increase of inbound calls to an emergency call centre during severe weather.

Using the NSWPAL as an example, the differentiator from a non-emergency facilities is that:

- the main focus is on public and officer safety,
- the business goal is to efficiently facilitate the provision of field resources while taking accurate information, through a high standard of training, staff coaching and mentoring to achieve a narrow standard deviation in call handle times,
- the real-time monitoring of the centre's performance to maintain the high level of performance,
- managing the facility within budget without sacrificing performance,
- the high level of system and process redundancy, all while
- having high political and media visibility.

In the context of an inbound emergency services call centre, the organisation has no control over the arrival rate which is contingent on externalities due to natural and human phenomena or actions. There can be a sudden and unexpected increases in the volume of inbound calls during an emergency in the community. It is important to note that due to the nature of the calls being received, the emergency services call centre business does not foster a repeat customer relationship culture. Calls are dealt with expeditiously, courteously and in a timely manner.

Betts et al. (2000, p.185) explain that 'call centre managers can have only a small influence on short-term performance'. This is one of the differentiators for emergency call centres since the short-term performance is significant to public safety in the community through the dispatch of frontline assistance.

In the above literature, modelling and simulation was in the context of multi-agency tabletop scenarios and mathematical modelling. Specific modelling of the interaction between the incoming calls and the CSRs was not found. This leads to the motivation for this thesis to create a parsimonious computer model to examine the effect of CSR parameters and different queue management methods on call centre performance by examining the interaction of the incoming calls and the CSRs.

2.3 Call centre performance measurement

A search of the Australian and international standards did not reveal standards for the measurement and calculation of call centre performance. The performance metrics to be used and the methods used to calculate these are left to the individual call centre managers. The literature reviewed by the researcher presents a number of methods.

There are a number of metrics that are used by the call centre industry (Duder and Rosenwein, 2001, Gans et al., 2003, Robbins et al., 2006, Koole, 2007, Cleveland and Mayben, 2001, Klungle and Maluchnik, 1997). The following were the most commonly identified from these sources:

- number of calls received or offered which is the total number of calls received in a specified time interval,
- number of calls answered or handled by a CSR,
- percent of calls abandoned before being served,
- Average Speed of Answer (ASA) being the average time calls wait to be answered by a CSR and excludes the waiting time for abandoned calls,
- the service level or Telephone Service Factor (TSF) being the percent or fraction of calls answered within the a time defined by the business,
- service level target (Klungle and Maluchnik, 1997) or Acceptable Waiting Time (AWT) which Koole (2007, p.59) defines as 'the target upper bound to the waiting time, very often equal to 20 seconds.' This is used in calculating the service level,
- Average Handle Time (AHT) per call and is generally made up of the talk time with the CSR, any time the customer waits on hold while the CSR seeks advice and, after call work undertaken by the CSR after hanging up from the call with the customer,
- agent occupancy which is the percent of the time a CSR spends handling calls and
- average call length.

As can be seen, these are not defined over a standardised or any time interval, although 30 minutes arises in the literature (Cleveland and Mayben, 2001, Pichitlamken et al., 2003, Gans et al., 2003) as being typical for non-emergency centres and 15 minutes being quoted for emergency centres (Lewis and Herbert, 2009, Kozan and Mesken, 2009, Atlason et al., 2004).

NSWPAL uses a 15 minute granularity for its performance metrics to achieve a higher level of response for emergency situations. Anything less that this could see the real-time management of the centre too sensitive to changes in externalities. This level of granularity is used for forecasting the inbound call rate and scheduling the CSRs. While a 15 minute increment is used in the model developed for this thesis, the model is capable of operating with a granularity both below and above this level as determined by the user.

The efficiency of the NSWPAL is driven by its performance metrics with the key metrics being service level, call answer time, call handle time which is made up of talk time and the time spent on after call work, abandonment and adherence to schedule. Of these, the two main drivers of efficiency that are monitored in real time are the service level and adherence to schedule. In this thesis service level and abandonment are examined and adherence is not covered. The measurement of adherence is a function of the computer-telephony integration system, and the workforce management system, both of which are described in the thesis Glossary[8]. The workforce management system is ancillary to the main call processing systems and is used to perform call forecasts and to build CSR schedules that take into account the call forecast, business rules and CSR needs.

2.3.1 Abandonment

Abandonment, or reneging, is where a customer terminates a call before reaching a CSR while waiting in a queue to be answered (Duder and Rosenwein, 2001, Gans et al., 2003, Mehrotra and Fama, 2003, Avramidis and L'Ecuyer, 2005). Mehrotra and Fama (2003) state that 'abandonment is one of the most hotly debated topics in call center management and research'. In the Section 2.3.2, methods of calculating the service level performance metric with and without abandonment will be shown.

Abandonment 'is an important measure of system congestion' (Gans et al., 2003,

[8] See p.1

p.8) and is also seen as a measure of customer patience (Brown et al., 2005, Zohar et al., 2002, Avramidis and L'Ecuyer, 2005). A caller will abandon the queue if their impatience equals (Garnett et al., 2002) or if it exceeds (Robbins et al., 2006) their wait time. Abandonment is also seen as a significant customer satisfaction indicator (Feinberg et al. (2000) cited in Mehrotra and Fama (2003)) and most inbound call centres that are focused on customer service pay attention to this statistic (Mehrotra and Fama, 2003).

Garnett et al. (2002) state that the effect of abandoning customers on service level must be considered in large call centres since it is only Automatic Call Distributor (ACD) abandonment statistics that reveal the customers perception of service quality.

Zeithaml and Bitner (1996) in Bennington et al. (2000, pp.163-164) provide
'eight explanations of different perceptions of waiting time:

(1) unoccupied time feels longer than occupied time;

(2) pre-process waits feel longer than in-process waits;

(3) anxiety makes wait seem longer;

(4) uncertain waits are longer than known finite waits;

(5) unexplained waits are longer than explained waits;

(6) unfair waits are longer than equitable waits;

(7) the more valuable the service the longer the customer will wait; and

(8) waiting alone feels longer than when waiting with a group.'

These give an insight into why people abandon call centre queues. Abandonment was shown to be a useful performance parameter for the following reasons:

- comparing mathematical models with and without abandonment, Garnett et al. (2002, p.8) show that 'the average wait and queue length are strikingly shorter when abandonment is taken into account',
- Duder and Rosenwein (2001) state that abandonments increase dramatically as the occupancy approaches 100% and that customers abandonments increase as ASA and queue lengths increase and
- Mandelbaum and Zeltyn (2007, p.3) give a good explanation of the effect of ignoring abandonment:

  > 'Ignoring abandonment can cause either under- or over-staffing: On the one hand, if service level is measured only for those customers who reach service, the result is unjustly optimistic - the effect of an abandonment is less delay for those further back in line, as well as for future arrivals. This would lead to under-staffing. On the other hand, using workforce management tools that ignore abandonment would result in over-staffing as actually fewer agents are needed in order to meet most abandonment-ignorant service goals.'

Gans et al. (2003, p.8) see abandonment as 'an important measure of system congestion' and Garnett et al. (2002) state that effect of abandoning customers on service level must be considered in large call centres since it is only ACD abandonment statistics that reveal the customers' (Garnett et al., 2002, p.8) perception of service quality. If abandonment is ignored service level is 'unjustly optimistic' as it results in less delay for those waiting in a queue and for future arrivals.' Also, workforce management tools result in understaffing since fewer agents are required to 'meet most abandonment ignorant service goals' (Garnett et al., 2002, p.8). In a model with and without abandonment, Garnett et al. (2002) show that the average wait and queue length are strikingly shorter when abandonment is taken into account.

They also note that performance in heavy traffic is sensitive to staffing level. The take home message from their paper is to include abandonments in performance metric calculations.

2.3.2 Service level

Service level, also called Telephone Service Factor (TSF) (Lam and Lau, 2004) is a 'key performance measure' (Klungle and Maluchnik, 1997, p.3) and is defined as the percentage of inbound calls or customers served within a specified time (Hishinuma et al., 2007, Saltzman and Mehrotra, 2004, Klungle and Maluchnik, 1997). Saltzman and Mehrotra (2004, par.5.1) refer to the time threshold as the 'Service Level Target' and Koole (2007, p.10) refers to it as the 'Acceptable Waiting Time (AWT)'.

Service level can be expressed as a number between 0 and 1, or as a percentage (Koole, 2007) and can be measured within specific time periods or aggregated over a day or a week (Mehrotra and Fama, 2003). However, where service levels within successive periods are aggregated the fraction of calls in each period should be calculated first and then used to calculate a weighted average of the service level for the aggregated period (Koole, 2007).

Service levels differ for commercial and emergency call centres. For the former it is generally 80% of the calls being answered within 20 seconds and for the latter it may be tighter such as 90% of the calls being answered within 10 seconds. This is the case at NSWPAL for the Triple Zero (000) queue, for emergency calls in New Zealand (Chen and Henderson, 2001) and was also noted by Atlason et al. (2004) for emergency calls.

In this thesis it was found that the method of calculating service level is open to question, there being a number of formulae and no apparent industry standard.

Consequently, the question as to whether or not abandoned calls should be included is open and up to the interpretation of the individual call centre managers.

In Section 2.3.1 the importance of including abandonment in service level calculations was shown (Koole, 2007, Garnett et al., 2002, Cleveland and Mayben, 2001, Zohar et al., 2002). Garnett et al. (2002) explain that the effect of abandonment on service level in heavy traffic must be considered for the management of large call centres.

Cleveland and Mayben (2001, pp.30-31) show four different methods that may be used to calculate the service level (SL). Table 2.1 explains the symbols.

$$SL_1 = \frac{C_{tAns} + C_{Ab1}}{C_{tAns} + C_{tAb}} \tag{2.1}$$

$$SL_2 = \frac{C_{Ans1}}{C_{tAns}} \tag{2.2}$$

$$SL_3 = \frac{C_{Ans1}}{C_{tAns} + C_{tAb}} \tag{2.3}$$

$$SL_4 = \frac{C_{Ans1}}{C_{tAns} + C_{tAb2}} \tag{2.4}$$

Of these, Cleveland and Mayben (2001) does not recommend Equation 2.2 as abandonment is ignored. They see Equations 2.3 and 2.4 as ‘an acceptable approach’.

It can be seen from Equations 2.3 and 2.4 above that if no calls abandon the queue then they give the same result as Equation 2.2 . This could happen if the analysis

Table 2.1: Symbols used in Equations 2.1 to 2.4.

C_{Ans1}	Calls answered in the service level time threshold
C_{Ab1}	Calls abandoned in the service level time threshold
C_{tAns}	Total number of calls answered
C_{tAb}	Total number of calls abandoned
C_{tAns2}	Calls answered after the service level time threshold
C_{tAb2}	Calls abandoned after the service level time threshold
C_{tEnt}	Total number of call entered into the queue in the time period being analysed

period is chosen such that there were few or no abandoned calls and could artificially inflate the service level due to a reduced denominator value. It could also mean that the call centre is optimally staffed.

Koole (2007, p.12) uses the following equation to calculate the service level which is in the form of Equation 2.4.

$$SL5 = \frac{Number\,of\,calls\,answered\,before\,AWT}{(Number\,of\,calls\,answered\,+\,Number\,of\,calls\,abandoned\,after\,AWT} * 100\% \tag{2.5}$$

He makes the point that 'callers who abandon after the AWT have received bad service, and therefore these calls are added to the number of calls for which the service requirement was not met'. Due to the different possible reasons for callers callers abandoning before the AWT, these are not included.

It was also found that Buist and L'Ecuyer (2005, p.560) include abandoned calls after a stated time in their Equation 2.6.

$$g(s) = \frac{E[X_{g(s)}]}{E[X + Y_b(s)]} \tag{2.6}$$

where $g(s)$ is the service level, X is the total number of callers served, s is the 'maximum acceptable waiting time in the queue', $X_{g(s)}$ is the number of contacts served within s, Y is the total number of contacts who have abandoned and $Y_{b(s)}$ is the number of contacts who have abandoned after time s. This equation is in the form of Equation 2.4.

PrarieFyre (2008)[9] classify abandon calls as either 'Calls Abandoned (Short)' or 'Calls Abandoned (Long)' with the time thresholds being a system configuration setting. They state that time threshold for the short abandon may be six seconds and such calls are 'NOT considered part of the Offered [*sic*] pool of calls' or the service level calculation. The long abandon calls are the number of call abandoned after the short threshold. PrarieFyre (2008) explains another type of call, 'Calls Interflowed', as those calls that are sent elsewhere, such as a voicemail system after a preset time. Their method for calculating the service level is shown in Equation 2.7

$$Service\ Level\ \% = \frac{ACD\ Calls\ Processed}{ACD\ Calls\ Offered} \tag{2.7}$$

where:

ACD Calls Processed =
    ACD Calls Handled by agents where the Time to Handle <
        Service Level Time +
    Calls Abandoned (Long) where the Time to Abandon <
        Service Level Time +
    Calls Interflowed (Long) where the Time to Interflow <
        Service Level Time

ACD Calls Offered =
    ACD Calls Handled by agents + CallsAbandoned (Long) +
        Calls Interflowed (Long)

[9] Accessed from the PrarieFyre home page, then Support, Documentation and Technical Documentation. No page numbers.

It is to be noted that in Equations 2.1 to 2.7 neither the time over which service level is calculated nor are the number of calls waiting to be answered a consideration.

The agent-based computer model built for this thesis provides graphical and tabular outputs in the form of Equations 2.2, 2.3 and 2.5 so that the differences between including and not including abandonment under different abandoning circumstances can be compared.

2.3.3 The Erlang C model

From a theoretical perspective and industry practice, The Erlang C model (Brockmeyer et al., 1948, Koole and Mandelbaum, 2002) is used as a means of calculating staff numbers performance metrics.

When using the Erlang C model to determine the staffing level, the service level figure is critical (Klungle and Maluchnik, 1997). However, Klungle and Maluchnik (1997, p.3) point out that a 'distorted picture of the true quality of service' occurs since times of low call volumes are weighted equally with those of high call volumes. This argument supports the use of a 15 minute interval for emergency services for forecasting and performance monitoring. Gans et al. (2003) advise that the Erlang C model 'allows for straightforward calculation of the stationary distribution of the delay of a call arriving' with the following assumptions:

- no-blocking,
- no-abandonment,
- constant arrival rate with a Poisson distribution and
- constant service rate with an exponential distribution.

To these Klungle and Maluchnik (1997) add assumptions of:

- a single queue with multiple servers,
- homogeneous servers,
- customers served on a first come first served basis, and
- unlimited queue length.

On these assumptions, Klungle and Maluchnik (1997) note that in a 'technology driven environment', many assumptions are invalid resulting in 'considerable overstaffing'.

The Erlang C queuing model is used 'to estimate stationary system performance of short ... intervals' (Gans et al., 2003, p.14). As indicated earlier in Section 2.3 the literature notes that these intervals are generally 30 minutes (Klungle and Maluchnik, 1997), however in NSWPAL, and other emergency services organisations 15 minutes is used (Lewis and Herbert, 2009, Kozan and Mesken, 2009, Atlason et al., 2004). The following equations (Gans et al., 2003, pp.15-16) facilitate the calculation of service level using the Erlang C model:

The offered load, which is measured in Erlangs, is a unit-less quantity is given by:

$$R_i \approx \lambda_i/\mu_i = \lambda_i E[S_i] \tag{2.8}$$

From this 'the associated average system utilization or occupancy (also called traffic intensity)' is calculated:

$$\rho_i \approx \lambda_i/(N\mu_i) = R_i/N \tag{2.9}$$

where, in Equations 2.8 and 2.9, i is the time period of interest such as 15 or 30 minutes, λ_i is the arrival rate for interval i, $E[S_i]$ is the expected service time, $\mu_i = E[S_i]^{-1}$ is the service rate for interval i and N is the number of agents.

Then, 'the steady-state probability that all N CSRs are busy' is given by:

$$C(N, R_i) \approx \frac{\sum_{m=0}^{N-1}(R_i^m/m!)}{\sum_{m=0}^{N-1}(R_i^m/m!) + (R_i^{N!})/1/(1 - R_i/N))} \tag{2.10}$$

which is also defined as 'the fraction of arriving customers that must wait to be served':

$$P\{Wait > 0\} = C(N, R_i) \tag{2.11}$$

From these, the ASA and the service level or TSF can be calculated:

$$\begin{aligned} ASA \approx E[Wait] &= P[wait > 0].E[Wait|Wait > 0] \\ &= C(N, R).\left(\frac{1}{N}\right)\left(\frac{1}{mu_i}\right)\left(\frac{1}{1-\rho_i}\right) \end{aligned} \tag{2.12}$$

$$\begin{aligned} TSF &\approx P\{Wait \leq T\} \\ &= 1 - P\{Wait > 0\}.P\{Wait > T|Wait > 0\} \\ &= 1 - C(N, R_i).e^{N\mu_i(1-\rho_i)T} \end{aligned} \tag{2.13}$$

where T is the acceptable waiting time (Koole, 2007).

2.3.4 Section comments and conclusion

The industry has developed a number of performance metrics and, of these, service level is seen as a key measure of customer service. Historically, A. K. Erlang (Brockmeyer et al., 1948) developed the theories associated with telephone system queuing in the early 1900s.

Call centre performance is measured throughout the day in 15 or 30 minute increments and have an aggregated measurement at the end of the day. Consequently, these systems are reset at the start of a new day which, until the first call is received.

This results in an anomaly when the service level is calculated using Equations 2.1 to 2.7. Simply, *zero calls answered/zero calls received or abandoned* is indeterminate and in this case *should* default to 100% . On the other hand, Equation 2.13 produces the correct result in this situation. However, it falls over if the offered load exceeds the number of agents, since the term $(1 - \rho_i)$ goes positive, sending the TSF negative. In a real call centre situation this can occur due to poor forecasting and/or scheduling or from an unexpected increase in the call volume. This has been accounted for by the researcher in the Erlang C component of the thesis model where, in such cases, the service level is set to zero.

For the thesis model, Equations 2.2, 2.5 and 2.13 are used to compare the different ways of calculating the service level. However, there is no restriction on the ratio of offered load and number of agents and, in the case of Equation 2.5, the customer patience level can be set to any value greater than zero to examine all possibilities.

2.4 Modelling and simulation as a research tool

From the literature reviewed, two salient areas of call centre performance analysis emerge; analytical or mathematical models, and computer simulation. This section considers mathematical modelling and describes the way computers are used for simulation. It concludes that because of the non-linear parallel processes involving human interaction, agent-based modelling (ABM) based on object-oriented programming techniques is a suitable approach for the model. The reasons for the selection of the computer simulation technique known as agent-based modelling for this thesis will also be explained.

2.4.1 Mathematical modelling

Mathematical models use equations to explain processes (Williams, 2006, p.14). They treat a problem as as entity and allow the major variables to be considered simultaneously (Blanchard and Fabrycky, 1990, pp.71-72). Mathematical models are seen as being 'of great benefit in system engineering and systems analysis' and provide a high degree of abstraction and precision Blanchard and Fabrycky (1990, p.126). They are implemented using mathematical procedures and may be used to predict outcomes. When used to study systems they often include 'probabilistic elements to explain their random behaviour' (Blanchard and Fabrycky, 1990, p.126).

Benefits of mathematical models (Blanchard and Fabrycky, 1990, pp.71-72) include:

- the comparison of solutions,
- indication of the type of data to be collected,
- prediction of future events, and
- the identification of areas involving risk and uncertainty.

2.4.2 Background to computer modelling

Over the past 20 years, social science modelling has undergone a significant evolution. Gilbert and Abbott (2005, p.859) indicated that the increase of computational power has enabled a shift towards 'a simulation approach to data' compared to the previously used estimation and optimisation approaches. They identify the different ways computers can be used to examine social structures and highlight agent-based modelling as an important change in social science since the implications of human actions in social structures can be examined. They also note that large amounts of data based on social structure evolution can be rendered visually to allow patterns to be easily detected.

Gilbert and Terna (2000, p.3) state that although statistical and mathematical models provide a formal base, the number of equations required to 'represent real social phenomena', particularly where non-linear relationships are present, and the often implausible simplifying assumptions can lead to misleading theories. With computer simulation, there is no difficulty in representing non-linear relationships although these can produce some methodological problems and 'it is possible to formalise complex theories about processes, carry out experiments and observe the occurrence of emergence' (Gilbert and Terna, 2000, p.2). They note that 'major growth' of computer simulation use in the social sciences is due to the development of agent-based models.

Klungle and Maluchnik (1997) see simulation as being a superior analysis tool to using analytical models and their associated assumptions. They see it being advantageous over queuing models, which mainly provide averages for performance measures, whereas simulation 'provides information on variability and extremes' (Klungle and Maluchnik, 1997, p.9). They state that new designs or policies can be investigated without disturbing the existing call centre operations in preparation for:

> 'Changes in call volumes;
>
> Introduction of new products and services;
>
> Process improvements;
>
> Revisions to service level goals.'

They give the following reasons as to why simulation should be used instead of analytical methods:

> 'Analytical models not available;
>
> The complexity of existing analytical models;

> Static results of analytical models are insufficient;
>
> Analytical models only provide averages, not variability and extremes;
>
> Analytical models cannot identify process bottlenecks or recommend design changes;
>
> Analytical models often cannot provide sufficient detail nor identify interactions;
>
> Animation is a better method of demonstrating results to management.'

2.4.3 Computer simulation and emergence

With computer simulation, a model is represented as a computer program which models qualitative and quantitative theories and processes, and although these can produce some methodological problems, there is no difficulty in representing non-linear relationships (Gilbert and Terna, 2000). A benefit of simulation analysis is that it provides a way of simulating future processes, identifying strengths and, any potential problems (Doomun and Jungum, 2008). Simulation facilitates emergence and development of macro-level responses from the action of individuals (Gilbert, 1999).

Emergence occurs where 'whole entities exhibit properties which are meaningful only when attributed to the whole, not its parts' (Hitchins, 1992, p.10) and that 'every system exhibits emergent properties which derive from its component activities and structure but cannot be reduced to them' (Hitchins, 1992, p.10). The output performance parameters of the thesis model, such as service level and ASA, are emergent properties derived from the inbound call rate, the speed at which the individual CSRs answer the calls, the number of calls waiting, the number of agents available and the individual agents' performance parameters.

Zeigler (1985) (cited in Gilbert and Terna (2000)) note that computer simulation has been used as a methodology in the natural sciences and engineering and is being used in the social sciences. The significant growth of computer simulation use in the social sciences is due to the development of agent-based models and their better appreciation for discovery models, understanding and formalisation (Gilbert and Terna, 2000).

Computer models flexibly allow the expression of ideas about process and the computer model is a representation of a social phenomenon that can be used to simulate such a process (Gilbert, 1999). Running the model under different input conditions or different inputs allows its behaviour to be observed as well as facilitating 'What if?' scenarios. Such models allow emergent properties of the system to be observed and studied from individual actions. Furthermore, the increase in computational power has enabled a move towards a data simulation approach (Gilbert and Abbott, 2005).

The operation and management of a call centre falls neatly into the social science category which is related to human social function and encompasses economics[10]. Since call centres necessarily have a high level of interaction between staff at different levels, between staff and customers, and the fact that the call centre is also an economic systems that deals with the provision and allocation of scarce resources to the customer service industry, computer modelling is suitable. The CSRs are human objects having properties such as their skill sets and functions, through training, mentoring and quality feedback to service their customers.

In the model described in this thesis, the interaction between the rate of incoming calls and the CSR's ability to service this and the management of the queues by the call manager under different management regimes are simulated.

[10] From The Macquarie Dictionary , Revised Edition, 1985.

2.4.4 Object oriented programming

A technique used for computer-based modelling is object-oriented Design (OOD) and is of particular interest in this thesis since it is the performance of the individual agents taking the calls in the model that drive the holistic performance of the model.

'Object oriented design is the technique used to architect software with groups of classes that interact with one another to solve a problem' (Roff, 2003, p.50) and object-oriented programming (OOP) is the implementation of the computer model created in the design phase (Roff, 2003).

Programming quality is improved by using OOP where 'agents become objects and events become steps activated by loops in the program' (Gilbert and Terna, 2000, p.13) and where objects are 'a piece of code containing data and rules operating on them' (Gilbert and Terna, 2000, p.13).

The three essential principles of OOD are classes (abstraction and encapsulation), inheritance and polymorphism. Abstraction is the general form of a class, encapsulation hides the functionality of an object from other objects and polymorphism is where more than one abstract class can have a common interface (Roff, 2003). Inheritance is where subclasses inherit the states and behaviour from the general class (Richter, 1999).

The advantages of OOD over procedural programming are:

- OOD hides functionality with the use of encapsulation and makes software easier to read (Roff, 2003),
- in procedural design, functions access other functions without any boundaries whilst OOD separates data and functionality 'into common classes that interact with each other to create a system' (Roff, 2003, p.53),

- everything is exposed in procedural design without any encapsulation. Because there are no defined interfaces, 'pieces of functionality begin to interfere with one another' (Roff, 2003, p.54) and business rules may be bypassed. On the other hand, OOD with encapsulation and exposure of objects via interfaces helps maintain software coherence. With encapsulation objects that store data, display data and carry out business logic can be created (Roff, 2003) and
- Object-oriented techniques avoid memory management problems and high level tools avoid both memory management and time synchronisation problems (Gilbert and Terna, 2000).

2.4.5 Agents or individuals

The literature does not clearly distinguish between individual-based models (IBM) and agent-based models as computer simulation techniques. However, the term IBM does appear to have an ecological background as explained by Grimm (1999, p.130):

> 'Models which use individuals as a basic unit have occasionally been used in ecology since the 1970s, but only since the visionary review of Huston et al. (1988) appeared a decade ago has individual-based modelling been an explicitly delineated approach of ecological modelling. Individual-based modelling refers in the following to simulation models that treat individuals as unique and discrete entities which have at least one property in addition to age that changes during the life cycle ...'

However, with time and advances in computer-based simulation, the distinction between individual- or agent-based modelling is not definitive with ABM also being known as IBM (Macal and North, 2005) and as seen in a subsequent article by Grimm et al. (2006, p.115) who explain that:

> '... autonomous individual organisms (individual based models, IBM) or agents (agent-based models, ABM) have become a widely used tool, not only in ecology, but also in many other disciplines dealing with complex systems made up of autonomous entities.'

An agent may be defined[11] as as 'a single or simple organism capable of independent existence' '... that which has the power to act' and an '... object producing or used for obtaining specific results; instrumentality' whereas an individual may be defined[12] as 'existing as a distinct, indivisible entity' ; 'pertaining or peculiar to a single ... thing' and where '... each is different or a different design from the others'; 'a single thing, ... instance, or item.'

In this thesis, the computer objects in the object oriented model are acting as agents for entities that have a specific role in the call centre process and so this thesis refers to agent-based models. Each agent has its own individual properties and individual methods and is able to act independently. In particular, there are:

- individual computer objects acting as agents for the CSRs,
- individual computer objects acting as agents on behalf of customers calling the call centre, and
- an individual computer object acting as an agent for the call manager.

2.4.6 Agent-based modelling (ABM)

Agent-based modelling is a newer subset of discrete-time simulation. It also involves resources, processes, activities, and is run under a simulation clock. Agent-based modelling uses software objects rather then traditional difference equations to model agents or entities and may model at a lower level. As such, it is a more relevant form of simulation for software developers such as the thesis author.

[11] From The Macquarie Dictionary, Revised Edition, 1985.
[12] From The Macquarie Dictionary, Revised Edition, 1985.

Bonabeau (2002, p.7280) explains that 'ABM is a mindset more than a technology' where a system is described 'from the perspective of its constituent units.' It is seen as an important change in social science since the implications of human actions in social structures can be examined (Gilbert and Abbott, 2005).

With OOD as a basis, ABM is where a 'system is modeled as a collection of autonomous decision-making entities called agents' (Bonabeau, 2002, p.7280). The agents have 'well-defined boundaries and interfaces', can observe and partially control their environment, have specific objectives, are autonomous and, can flexibly control problems (Jennings and Bussmann, 2003, p.4).

Wooldridge and Jennings (1995, pp.4-5) explain the 'relatively uncontentious' and general use of an agent in software with the properties of:

- Autonomy: control own actions without human intervention.
- Social ability: agents interact with each other.
- Reactivity: perception of and reaction to, in a timely manner, their environment.
- Pro-activeness: 'exhibit goal-directed behaviour by *taking the initiative*.'

Benefits of ABM seen by Bonabeau (2002) are:

- emergent phenomena capture,
- providing a way to describe the system naturally, and
- its flexibility.

2.4.7 Computer programming tools

The literature revealed that there are many computer modelling applications or tools. Furthermore, Gilbert and Terna (2000) explain that there is no single best way to build agents and that the method depends on the purpose of the simulation. All agent designs include environmental input mechanisms, a means to store a history of previous inputs and actions and a mechanism for devising what is to be done next, for carrying out the actions and for distributing the outputs.

The following is a list of applications found in the literature that can be used to create ABMs:

- MATLAB®[13] (Lewis et al., 2010).
- Buist and L'Ecuyer (2005) describe a Java library called ContactCentres that is used to write contact centre simulators. They also note that specialised software can be used such as ccProphet[14] and the Arena Contact Center Edition from Rockwell[15].
- Extend V6[16] (Kozan and Mesken, 2009).
- Gilbert and Terna (2000) identify the following tools that are suitable for implementing object-oriented programming systems and explain their use and the situations in which they are suitable:
  - Swarm[17],
  - MAML (Multi-Agent Modelling Language)[18];
  - SDML (Strictly Declarative Modelling Language)[19];
  - SIM_AGENT[20];
  - StarLogo[21].

The computer model in this thesis was built using the MATLAB® application which has specific functions for agent-based programming.

[13] See http://www.mathworks.com/products/matlab/
[14] See http://www.novasim.com/CCProphet
[15] See http://www.arenasimulation.com/ from Rockwell
[16] See http://www.extendsim.com/sols_simoverview.html#discreteEvent
[17] http://www.swarm.org/index.php/Main_Page
[18] See http://www.maml.hu/maml/initiative/index.html
[19] See http://cfpm.org/sdml/
[20] See http://www.agents.cs.nott.ac.uk/drupal/node/19
[21] See http://education.mit.edu/starlogo/

2.5 Chapter conclusions

The main problem addressed in the literature is that of maximising the use of resources because of the high cost of labour associated with call centres and customer service. The emergency call centre also has budget restrictions. However, it's main function is to obtain information that will effect the timely dispatch of field resources while providing a high level of customer service to the affected customer and meeting the strict service level. This is one of the differentiators of the emergency call centre and another is the call arrival rate which can change suddenly and unexpectedly in an external emergency.

The emergency services call centre fits the profile of the general call centre and can be analysed analytically in a similar manner. However, it is also differentiated by two important aspects; timeliness and caller state. The callers may be in a state of high anxiety due to the situation in which they are involved and, irrespective of this, the agent must extract the information required to facilitate the timely dispatch of resources.

The literature search revealed only minimal research being undertaken specifically in the area of emergency services call centre modelling although there is general acknowledgement of them in the literature. These models were mainly mathematical and in the few instances where ABM was used, it was to model the tactical response of a number of emergency disciplines and included the call centre spatial and environmental aspects.

This thesis specifically uses an agent-based model to emulate the relationship between inbound calls, call allocation regimes and call taker properties and processes with a view to maximising the emergent performance. This facet of call centre modelling and simulation was not in the literature.

The call centre is part of a social system where CSRs interact with customers to produce an outcome. The literature identified that the use of ABM techniques for simulation is well suited to the computer model in this thesis with the reasons being summarised as:

- the increase in computational power has enabled a move towards a data simulation approach Gilbert and Abbott (2005),
- the implications of human actions in social structures can be examined (Gilbert and Abbott, 2005),
- simulation provides information on variability and extremes (Klungle and Maluchnik, 1997),
- new designs or policies can be investigated without disturbing the existing call centre operations (Klungle and Maluchnik, 1997),
- strengths and potential problems can be identified by simulating future processes (Doomun and Jungum, 2008) and
- simulation facilitates emergence and development of macro-level responses from the action of individuals (Gilbert, 1999).

In the next chapter the processes used to gather and analyse NSWPAL data will be discussed and the results presented. The discussion includes the effect of unexpected exogenous events on queue performance.

Chapter 3

APPROACH AND DATA

3.1 Introduction

It is important that emergency services organisations provide rapid response to requests for assistance from the community. One such organisation is the NSW Police Force in Australia. The NSW Police Assistance Line (NSWPAL) is this organisation's main telephony portal for those seeking assistance. NSWPAL operates on a 24-hour basis for each day of the year and has call queues to take urgent and non-urgent calls from the NSW community. These calls are taken by trained Customer Service Representatives (CSRs). These staff are rostered according to the queues' forecast inbound call volumes, the NSWPAL business rules and the CSR preferences. Not all CSRs are trained for both queues. Overall, the call centre meets is service level goals on both queues however, there are times when exogenous events cause an unexpected increase in calls. The impact of this is that the time to answer the calls increases and the service level drops. In such times, the managers make decisions in an effort to improve the situation.

To answer the thesis research questions a quantitative research approach was taken using de-identified data obtained from the NSWPAL urgent and non-urgent call queues together with an agent-based computer model which was designed and programmed by the researcher. The former was analysed to provide summary data and to identify times of unexpected increases in call volumes due to exogenous events.

The latter was used to simulate such instances and determine if different queue management processes can be used to improve the call centre performance. In this chapter, the NSWPAL urgent queue may be referred to as Triple Zero (000) and the non-urgent queue as 131444 which are the telephone numbers customers call for assistance.

This chapter discusses the processes used to extract and analyse the relevant inbound call data to the NSWPAL and highlights the sudden changes that can occur in an emergency services call centre. Parts of this chapter were published in proceedings of the MODSIM 2007 International Congress on Modelling and Simulation conference (Lewis et al., 2007) and the 6th International Conference on Information Technology and Applications conference (Lewis and Herbert, 2009).

3.2 Philosophical approach to the research

The two primary research classes are quantitative and qualitative (Dawson, 2009, Leedy and Ormrod, 2001). The quantitative research method deals with 'explaining, predicting and controlling phenomena' (Leedy and Ormrod, 2001, p.101) or using numerical measurement scales (Dawson, 2009). Quantitative research is also referred to as 'traditional, experimental, or positivist' (Leedy and Ormrod, 2001). On the other hand, qualitative research is used to provide answers and increased understanding in a given area without producing an explanation (Dawson, 2009, Leedy and Ormrod, 2001). Quantitative research is also referred to as 'interprative, constructivist or postpositivist' (Leedy and Ormrod, 2001).

Since this thesis deals with the measurement of call centre performance and the controlling of the computer model parameters to measure numerical results, and does not involve humans or animals, the quantitative research method was chosen.

Although all data are numerical and de-identified, ethics approval was sought and given by the University of Newcastle, Australia, Human Research Ethics Committee (Reference No: H-532-0707) and approval to undertake the research using NSWPAL data was given by the NSW Police Force.

3.3 Data collection and preparation

Data were collected for the NSWPAL Triple Zero (000) or urgent call queue for the period 1 February 2005 to 31 December 2008 and the 131444 or non-urgent call queue for the period 1 January 2005 to 31 December 2008, these being the analysis periods. The NSWPAL Triple Zero (000) and 131444 queue reports were available in PDF format. These reports were not prepared by the researcher.

Data for these reports were collected by the call centre's computer-telephony integration (CTI) system in real time and stored in a database. The queue reports were run against this database using the BusinessObjects™[1] application by the NSWPAL analysts and technical staff and stored centrally for the centre managers. The daily data were presented in 15 minute blocks from midnight to midnight giving a maximum sample size of 96 blocks for each day for each queue. Data were extracted from these reports by the researcher and stored in spreadsheets. When doing so, care was taken to ensure allowances were made for changes in time at the beginning and end of daylight saving. There were, however, times when no calls were received in a 15 minute block and this was reflected in the report with those blocks missing. This is a function of the CTI system which only deals with actual call received. Another aspect of the reports was that the number of CSRs in a given 15 minute block was not reported. This is because there are two classes of CSR. One takes only non-urgent calls and the other takes both urgent and non-urgent calls. Conse-

[1] See: http://www.sap.com/solutions/sapbusinessobjects/index.epx

quently, the number of CSRs available for each of the queues varies with the type and volume of inbound calls in any 15 minute period. As will be seen, the number of CSRs can be set and varied in the model.

The data were extracted from these reports by the researcher and placed into spreadsheets arranged as separate workbooks[2] for the Triple Zero (000) and 131444 data. Each of these workbooks had a separate worksheet for each calendar month and these spanned the analysis periods. Each worksheet contained data for the calendar month organised as 15-minute blocks in contiguous days. Each worksheet had columns with the following data:

- date,
- 15 minute period from time 00:00 to 23:45 for each of the days,
- queue name,
- number of calls entered,
- number of calls answered,
- number of calls answered in less than 27 seconds for the non-urgent queue or 10 seconds for the urgent queue,
- number of calls abandoned,
- maximum time to answer formatted as minutes:seconds,
- maximum time to abandon formatted as minutes:seconds,
- average speed to answer formatted as minutes:seconds and
- Telephone Service Factor (TSF) as a percentage.

A script[3] was written to insert any missing 15 minute blocks over the analysis periods together with zero for data in all columns except the date, time, queue name and TSF. The TSF was set to 100% which agrees with the Erlang C calculation for TSF

[2] In this thesis Microsoft® Excel was used. See: http://www.microsoft.com/en/us/default.aspx
[3] In this thesis, Microsoft® Visual Basic for Applications (VBA) was used

(Gans et al., 2003, Koole, 2007) which was discussed in Section 2.3.3 of Chapter 2.

Although the focus was on analysing the number of calls entered into the queues, the other parameters in the above list were used in conjunction with the model to determine its efficacy in identifying alternate efficient queue management processes.

3.4 Analysing the data

With a 15 minute granularity, it is possible to access any 15 minute block over the analysis period for each of the two queues from the spreadsheets. Although the model is capable of simulating any of these 15 minute blocks in the analysis periods, this thesis focusses on finding ways of optimising the CSR resources for different inbound calls volumes and CSR parameters. To do this for all 15 minute blocks over the analysis period for both queues required the creation of a large database with more than 250,000 entries. So instead, it was decided to prepare daily summary statistics for the queues over the analysis periods and use these to examine *typical* daily data for use by the historical data call generator in the thesis model as a basis for creating the historical urgent or non-urgent inbound calls. These summaries were prepared by the researcher using a script.

To produce the final daily summary statistics for the mean number of calls entered and their associated SDs, a program was written and run by the researcher[4]. The daily summary results are shown in Appendices A.1 to A.4 and in Figures 3.1 to 3.4 for each of the queues. For the non-urgent queue over the period January 2005 to December 2008, Appendix A.1 shows, in 15 minute blocks, summary means and Appendix A.2 shows the SDs. For the urgent queue over the period February 2005 to December 2008, Appendix A.3 shows, in 15 minute blocks, summary means

[4] MATLAB® was used to write the program since a later version of Microsoft® Excel licensed to the to the researcher no longer supported VBA.

and Appendix A.4 shows the SDs. Using these results, Figures 3.1 and 3.3 show the average number of calls received in each of the urgent and non-urgent queues respectively in quarter hour intervals for each of the seven week days over the analysis periods. Similarly, Figures 3.2 and 3.4 show the SDs.

3.4.1 The non-urgent queue

The non-urgent queue exhibits a similar daily pattern to those found in the literature that deal with the commercial world. See Gans et al. (2003), Brown et al. (2005) and Cleveland and Mayben (2001).

Figure 3.1 shows that the mean volume of calls, largely in the daylight hours decreases as the week progresses from Monday to Sunday and each day has a morning and afternoon peak. During the nights, the call volumes are comparatively low.

With respect to the means, Monday mornings are busy due to people reporting incidents that occurred over the weekend. This standard deviation variability for Mondays and Tuesdays can be explained as being due to public holidays. When there is a public holiday on a Monday, the non-urgent queue tends to be quiet. However, the following Tuesday picks up the load after people return home or return to work.

3.4.2 The urgent queue

The urgent queue data shows a different pattern to the non-urgent queue with different profiles for the Friday afternoon to Sunday morning and the rest of the week. Here, the larger SD on Saturdays and Sundays are due to weekend activities and the early hours of Mondays shows variability that is most likely due to those days being public holidays.

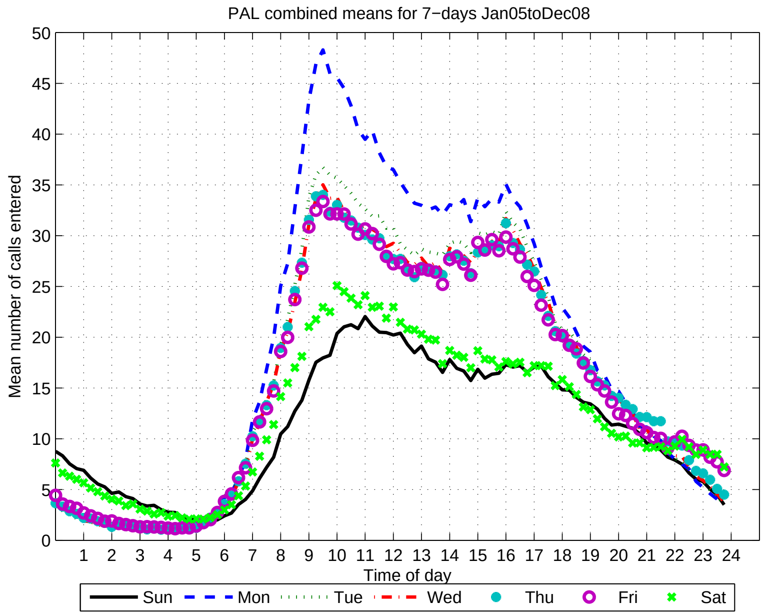

Figure 3.1: 131444 7 day data means over the analysis period.

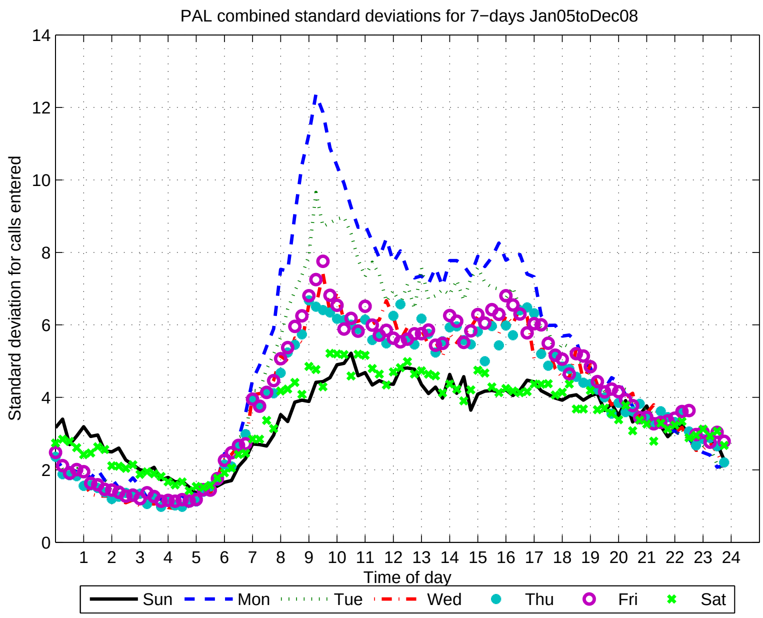

Figure 3.2: 131444 7 day data SDs over the analysis period.

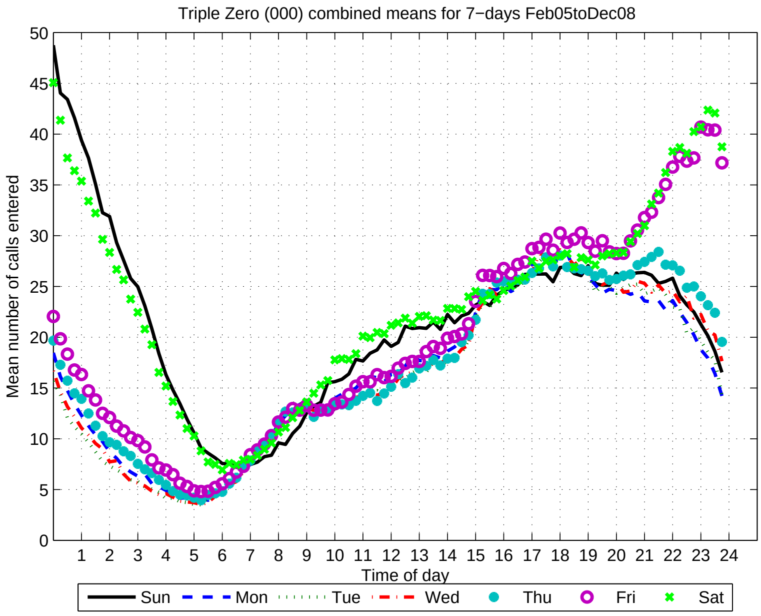

Figure 3.3: Triple Zero (000) 7 day data means over the analysis period.

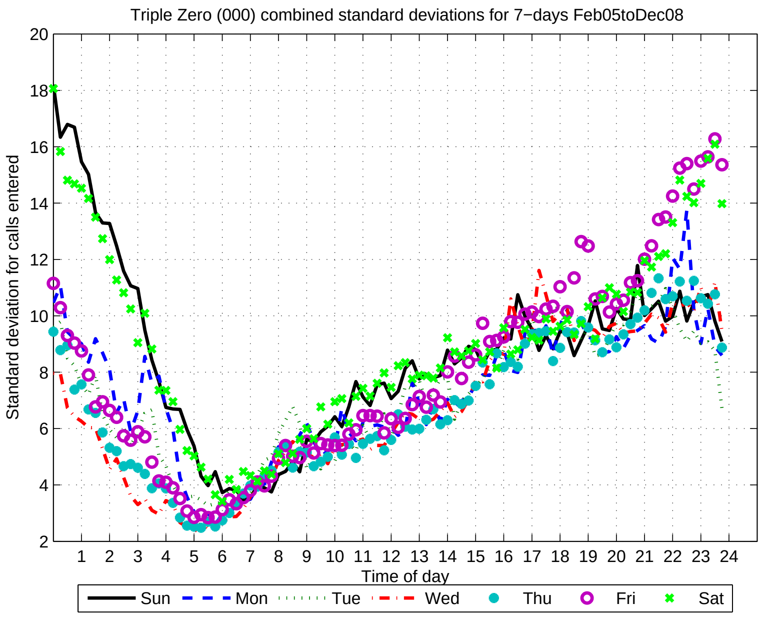

Figure 3.4: Triple Zero (000) 7 day data SDs over the analysis period.

The literature did not report a daily call profile for a police-related emergency call queue. However, one reference (Bieger et al., 2009) described the Brazilian metropolitan emergency response system for medical emergencies. It showed a figure that illustrated the average number of emergency calls per hour that was similar in shape to the *non-urgent* queue described above.

No detailed analysis of the emergency inbound calls to a police facility was found and this is an original contribution of this thesis.

3.5 Exogenous events

Unexpected exogenous events can occur that affect an emergency services call centre. and Friday nights and Saturday mornings are usually a busy period for the urgent NSWPAL queues.

In July 2007 one such event caused a drop in performance of the urgent queue over the evening of Friday 6 July 2007 and morning of Saturday 7 July 2007. Both urgent and non-urgent queues were functional. In Figure 3.5, can be seen the forecast calls and the received calls and the fact that the forecast was very good. However, the urgent queue tells a different story. With reference to Figure 3.6, for the period 10 pm to 6 am the number of calls received far exceeded the forecast volume and in particular, the period 11 pm to 1 am service level was such that it was not possible to answer the calls within 10 seconds. Since for each queue, the number of CSRs is related to the expected call rate, the capability to meet the extended peak was not available. The problem for the Team Leaders on duty was how best to optimally manage the situation with the available resources. The options available to the team leaders are limited and include moving CSRs between queues, changes in CSR meal breaks, calling in additional staff and extending the shifts of CSRs. Changing

CSRs between queues can only occur if the other queues are able to maintain their performance although priority is given to the urgent call queue. The latter two options are at a financial cost to the NSWPAL and so requires management approval. Data for this event are included in Appendix B.1 and Appendix B.2.

3.6 Concluding remarks

This chapter explained that the quantitative research approach is best suited to the aim of this thesis to model and simulate and emergency telephone call centre.

To identify with real situations for use in the ABM, data were extracted from standard NSWPAL business management reports and analysed to produce daily summary statistics for the mean number of calls received in each of the urgent and non-urgent queues over a contiguous period of four years. The associated SDs were also presented and can be used in the historical call generator component of the ABM to provide controlled variability of the number of calls in the historical call stream. Although the historical call generator deals with summary data, specific data can be accessed from the spreadsheets and fed in to the model manually.

NSWPAL is a non-commercial entity and the inbound calls are the result of exogenous events in the community and not due to advertising campaigns such as those found in the commercial arena. So, it is interesting to note that the daily summary data pattens for both the urgent and non-urgent queues are highly predictable. The data also demonstrated the sudden volatility in inbound call volume that supports the use of modelling and simulation as a tool for examining different ways of managing the calls.

The next chapter covers the development of the prototype and final agent-based models.

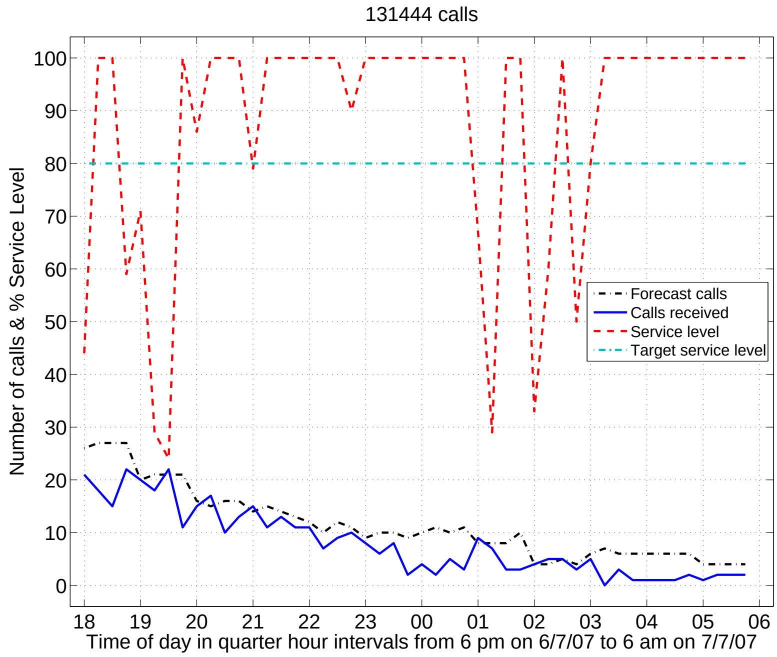

Figure 3.5: 131444 calls between 6 pm on 7 July 2007 and 6 am on 8 July 2007.

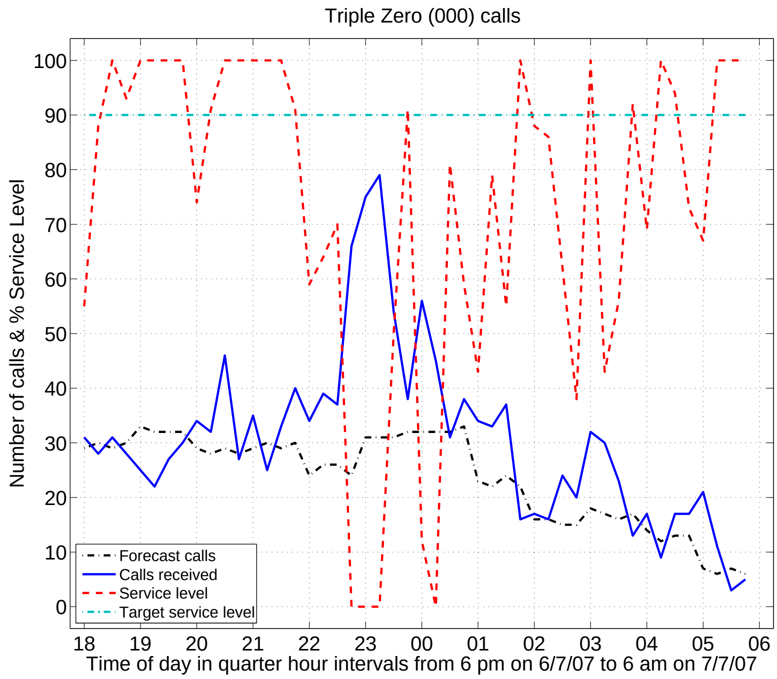

Figure 3.6: Triple Zero (000) calls between 6 pm on 7 July 2007 and 6 am on 8 July 2007.

Chapter 4

THE AGENT-BASED MODEL

4.1 Introduction

This thesis involved the building of an agent-based computer model that allowed variation of agent and call parameters together with the testing of different management regimes to maximise call queue service levels of an emergency call centre. This chapter explains the development and operation of the agent-based model. When discussing the models, the term Call Taking Agent (CTA) has been used to distinguish the computer agent from the human CSR. Two models were created: the first was a basic prototype model and the second was a more complex final model. The models used different techniques to create the agents. Following the successful creation of a prototype, the final model was developed incrementally by the researcher using evolutionary prototyping (Dawson, 2009).

The prototype and final versions and components of the call centre models were written using the MATLAB®application[1]. Each of the functional sections of the final model were written and tested in succession by the researcher.

To determine the impact of a parameter on the performance of the call centre model, the researcher chose to design the model such that only one of the user selected or set parameters was varied when the model was run.

[1] See http://www.mathworks.com

An important aspect of the prototype model and final model is that each time step of the program corresponds to one second of real time. This means that the simulated performance of a model can be gauged against actual call centre data.

This chapter explains the development and operation of the prototype model and the final model, their purpose and objectives and how they were compared. First the structure of the prototype model is described. A detailed description of the final model and its operation follows including an overview, assumptions, the inputs and outputs, the utility of the graphical user interface, and the generation of the inbound calls. Each of the models was run independently and their results were compared.

Parts of this chapter were published in proceedings of the MODSIM 2007 International Congress on Modelling and Simulation conference (Lewis et al., 2007), in proceedings of the 5th International Conference on Information Technology and Applications conference (Lewis et al., 2008) and in the World Review of Science, Technology and Sustainable Development Journal (Lewis et al., 2010).

4.2 Purpose and objective of the model

The purposes of the model included the simulation of the operation of an emergency call centre under normal operational conditions based on user-defined conditions, from historical or user-defined data under conditions where unexpected exogenous events occur.

The objectives of the model included the determination of whether call centre performance could be improved under these conditions and to design a model that was calibrated against real time where each time step of the program corresponded to one second of real time.

Whereas inbound calls to the emergency call centre are independent of the call centre, the internal operational aspects are controlled by managers and depend on call volumes, staff scheduling, staff performance and the business rules. In this model, the call allocation process and CTA performance parameters were used as drivers to examine the model's performance under test and real situations. In Chapter 5, the performance of the model is compared with the Erlang C model that was discussed in Chapter 2.

4.3 Model verification

Verification of the final model was undertaken on two levels. The first was by comparing its results with those of the prototype model for the same input data and the second was by comparing its performance against NSWPAL data. The latter is covered in the next chapter.

4.4 The prototype model

The prototype agent-based model was a simple program the purpose of which was to model the essence of the call taking process. Model parameters were changed by changing the program code.

This model consisted of agents for incoming calls, CTAs and a call manager each of which had individual and programmable attributes and methods. The CTA parameters were the time taken to pick up the call, time taken to answer the call and time taken in after call work (ACW) to complete the job once the caller had hung up. There were state flags that specified whether the CTA was ready to take a call, was picking up the call, was talking, or was in ACW. Incoming calls were generated by the program and placed into the call queue. Each call was given a unique identifier so that it could be uniquely referred to at a later time. The call queue contained the history of the simulation including the call's time into the queue, time call answered, time call ended, call status, and the CTA that answered the call.

Overseeing the model was a call manager, the function of which was to control the timing, generate the calls, manage the call queue and calculate and display the results. In this version of the model, the agents were created as rows in a matrix with the columns containing the attributes and the results of any calculations. There was also a call progress matrix that shadowed the main queue and was used as a scratchpad for timing calculations by the manager. All CTAs had the same operating parameters, were autonomous when dealing with a call and only communicated with the call manager and not with each other. The incoming calls were generated at user-defined equi-spaced time steps. The CTA and call states are shown in Table 4.1.

The structure of the program is shown in Figure 4.1. It consists of an outer loop and an inner loop. The outer loop changes a selected parameter between two limits at defined steps. The inner loop runs the simulation for each parameter step for the period chosen. At each time step, CTA agents are checked for readiness to take a call, calls are entered into the queue, calls are checked to see if they will abandon, unanswered calls are allocated to the first available CTA and calls are processed by the CTA through the pick-up, talk and ACW phases. Each time step of the program corresponds to one second of real time.

A preliminary computer model was built by the researcher using the Java programming language. However, due to the advanced functions and plotting capabilities, the prototype model was implemented using the MATLAB®application. A spreadsheet was used by the researcher to calculate the times at which certain milestone events occurred and the model was run to fine tune the program timing loops and

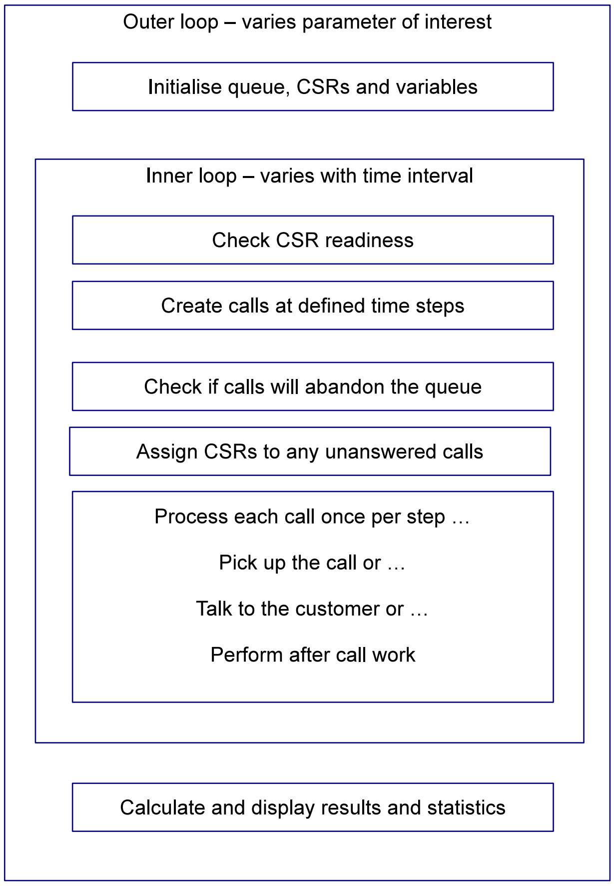

Figure 4.1: Prototype program structure.

logic until both agreed. Although the model calculated all of the service levels identified in Chapter 2, only the results for results for Equations 2.2, 2.3 and 2.5 were selected to highlight the differences in choosing different calculation methods.

4.5 The final model

Using the prototype model as a basis, the final model was developed incrementally where one section was built and tested before the next section. The final model was written with the MATLAB®application with the agent class definitions being implemented using the *classdef* function[2].

[2] See http://www.mathworks.com/access/helpdesk/help/techdoc/matlab_oop/bree1u6.html

Table 4.1: Prototype CTA and call states.

CTA states	Call states
Ready	Entered into queue
Call picked up	Allocated to CTA
Talking	Picked up by CTA
ACW	Pick up end
Make ready	Talking to CTA
	Talk end
	CTA on ACW
	ACW end
	Abandoned queue

The final model has a GUI[3] and three classes of agents. A manager monitors the queues, monitors the CTAs and allocates the calls in accordance with a specified method. Calls enter the queue and abandon if the wait time is greater than or equal to the abandon time set by the user. CTAs are allocated calls by the manager and work autonomously to service the calls. The model has a graphical interface which is the main input for the model and it drives the model's initialisation, creation of all of the agents and mode of operation.

The model includes two call generators. One is included in the model and is provided for the user-specific data and parameters. The other is a separate program that uses the urgent and non-urgent queue summary data and is discussed in Section 4.7.

Figure 4.2 shows the UML class diagram for the final model. For clarity, the agents' attributes and methods are shown in plain english rather than their program code.

Although there is only one manager in this model, the abstract CTA class could be used to create a team leader class as a middle manager should this model be extended.

[3] See p.79

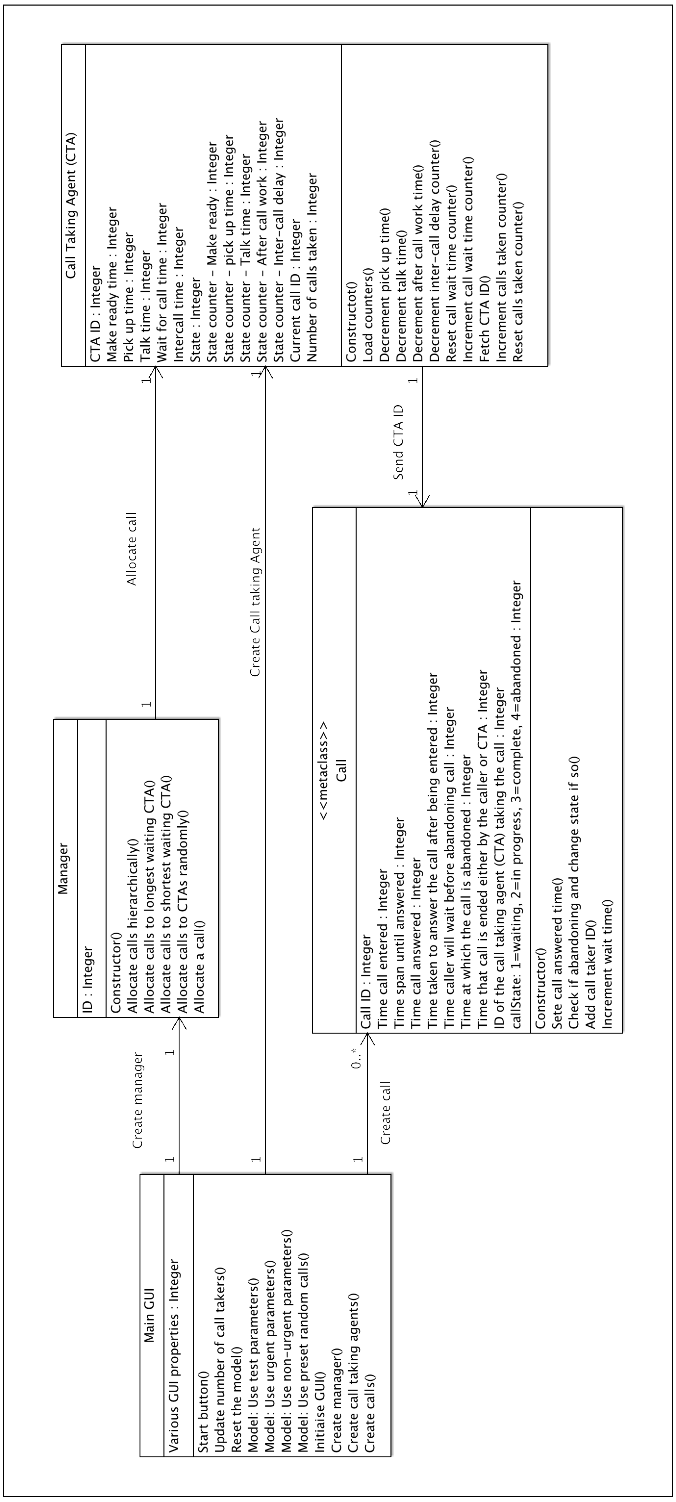

Figure 4.2: The final model UML class diagram.

Both the call and CTA classes are concerned with timing. The call agents monitor the times such as when they are answered, how long it took to be answered and whether it is time to abandon, while the CTA agents count down a series of successive counters when processing calls. In addition, CTAs transfer their unique identifier to the calls they process. The CTAs are homogeneous in their attributes and work autonomously. Homogeneity is essential to the model otherwise it would not be possible to determine the impact of a CTA parameter on the emergent performance.

For the CTA parameters, provision has been made to select the abandon time, call pickup time, talk time and after call work time. Of these, only the talk time has been activated for this thesis since it represents the greatest impact on the call handle time. Depending on the options chosen, the talk time can be varied between two limits in user-specified steps.

Data were collected during each simulation run and together with the progress status, were written to the command window. Depending on the options selected, tabular output is written to the command window at each parameter and/or time change. There are separate status tables for the CTAs and the calls. At the completion of a simulation run, service level is plotted for Equations 2.2, 2.3 and 2.5.

4.5.1 Final model overview

Figure 4.3 shows an overview of the final model. From the model's GUI, the user selects the call data source from user-defined data or the historical repositories, sets the call and CTA parameters and starts the model. Based on the CTA parameter to be examined, the main timing loop checks the state and processes each call and checks the state of and processes each CTA. First, the calls are checked to see if they will abandon. If waiting, the manager allocates them to a ready CTA. Next, based on their current state, each of the CTAs undertake activities to pick the call up, talk to the caller, perform ACW and wait a mandatory time before being ready for the next call. The CTA and call states are shown in Table 4.2.

Table 4.2: Final model CTA and call states.

CTA states	Call states
Make ready	Entered
Ready	Pick up
Pick up	End talk
End pick up	Finished
Talk	Abandoned
End talk	
ACW	
End ACW	
Inter-call delay	
End inter-call delay	

Throughout the process the manager, the calls and the CTAs maintain the call and CTA data repositories. At the end of the main timing loop the performance statistics are calculated and presented, and the results are plotted.

The assumptions used in the prototype and final models are:

- all calls enter a queue,
- there is no blocking of calls due to insufficient resources,
- the model operates where one time step of the program corresponds to one second of real time,
- the CTAs are homogeneous with respect to their operating parameters,
- calls enter at a constant rate which is determined by the user,
- the CTAs wait a mandatory 10 time steps between calls,
- there is a single manager, and

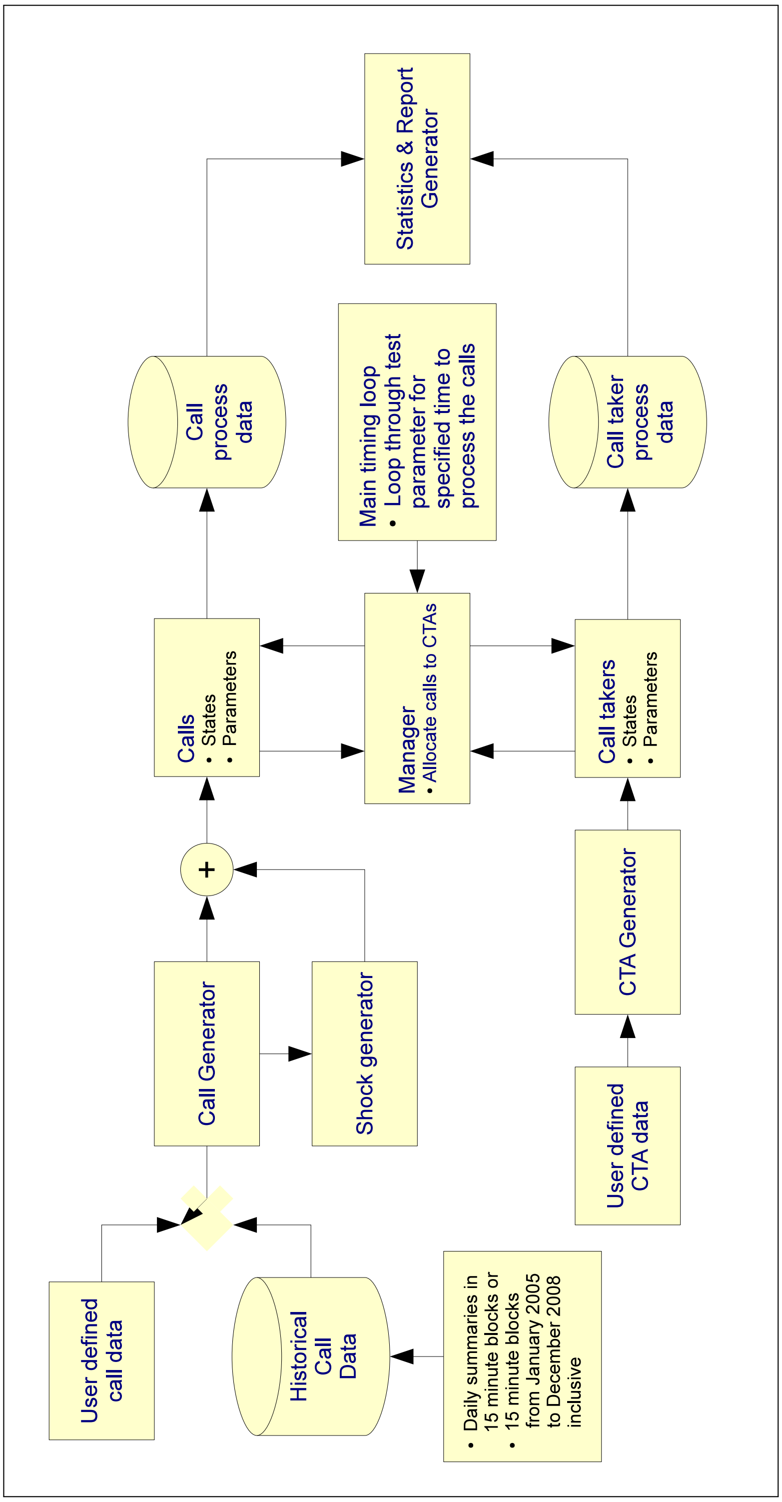

Figure 4.3: The final model overview.

- calls remain in their queue until answered or until they abandon and do not flow to other systems such as voice mail.

The following are the main inputs to the final model and depend on the model option chosen:

- the number of time steps,
- the AWT,
- percent of calls to be answered within the AWT,
- number of calls to be entered,
- number of CTAs,
- call abandon time,
- CTA call pick up time,
- CTA talk time range,
- CTA ACW, and
- CTA call allocation method.

The following are the main outputs from the final model:

- total number of calls entered,
- total number of calls answered within the AWT,
- total number of calls answered after the AWT,
- total number of calls abandoned,
- total number of calls abandoned within the AWT,
- total number of calls abandoned after the AWT,
- service level using Equation 2.2,
- service level using Equation 2.3,
- service level using Equation 2.5,
- service level using Equation 2.7,
- service level using Equation 2.13,

- average time to answer the calls (ASA),
- average waiting time, and
- graphical output for the last seven items.

4.5.2 The graphical user interface

Central to the model and its operation is the Graphical User Interface (GUI. The GUI has been designed such that where parameters or options are not required for a specific simulation, these are made invisible. The GUI is shown in Figure 4.4 with the main panels and their components visible.

Earlier agent-based models created by the researcher relied on data and parameters being changed in the program code prior to running the program. Due to the number of parameters and the number of simulation scenarios, the researcher decided to develop a GUI as the front end of the model. One advantage was that the values associated with a particular simulation remained visible on the computer screen and not hidden in code. Another was that it was also easy to make small changes to the input values and monitor the changes in the results. The interface was created using the Graphical User Interface Development Environment (GUIDE) tool[4]. Briefly, a canvas was provided onto which the various objects were placed and the initial properties of the objects were set within the interface.

Callback functions were activated when the user clicked on a control or changed a parameter in the GUI. With this as a basis, the create and callback functions were expanded and the other external functions that were called from the GUI were written. The following sections discuss the GUI panels.

[4] http://www.mathworks.com/access/helpdesk/help/pdf_doc/matlab/buildgui.pdf

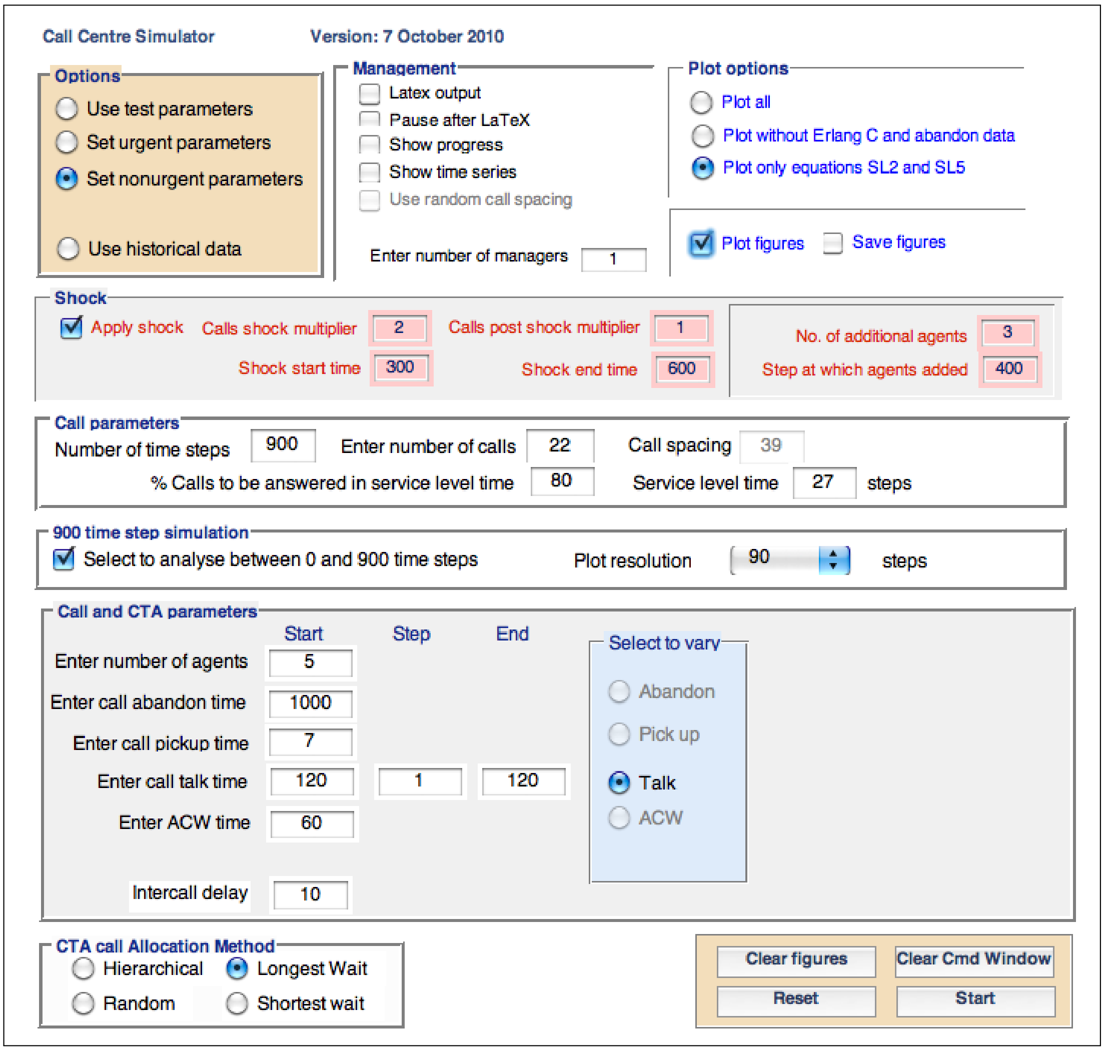

Figure 4.4: The final model graphical interface showing the non-urgent mode.

The Options panel

The Options panel consists of 4 radio buttons. *Use test parameters* was used to develop the timing sequence for the model and has been retained. *Set urgent parameters* is used to model the urgent queue, *Set nonurgent parameters* is used to model the non-urgent queue. The last button *Use historical data* invokes a separate GUI that is used to access the NSWPAL historical summary statistics, previously discussed in Chapter 3 and generate an inbound call series.

The Management panel

The *Management panel* provides the model's general management and housekeeping. Although it was possible to have any number of managers, for this thesis, a single manager was used to allocate calls to CTAs in accordance with the *CTA call Allocation Method*.

Utilities were provided to assist in the preparation of the results for this thesis. By selecting *Show progress* results for each call and each CTA were printed to the command window at the end of each single time step. This facility was used by the researcher during the model's development to ensure that the CTA counters were operating correctly. To view the time series, the *Show time series* is selected.

To facilitate formatted tables for this thesis, the LaTeX[5] *output* option wrote LaTeX code to the command window after each of the results table allowing them to be copied into any LaTeX source file. *Pause after LaTeX*, pauses the model after each LaTeX table is written. This was necessary for long runs as the command window was of insufficient length to include all results.

In the next chapter, results will be presented for Equations 2.2 and 2.5 and there is a facility, *Plot only equations SL2 and SL5*, to provide results for only these.

The Plot options panel

This panel provides a number of different types of figure outputs. Provision was made for comparing the simulations against the use of the Erlang C model and viewing the abandon call rate. Of particular interest was the ability to focus on two common methods of calculating the service level. The *Plot without Erlang C*

[5] See, for example, `http://www.latex-project.org/`

and abandon data option were used to simplify the results figures. The user has the option of plotting or not plotting the output responses. *Plot figures* was deselected where timing information was required without a plot of the results.

The Shock panel

The shock facility allows a block of calls to be added as a multiple of the number of calls set in the call parameter panel. The user sets the start and end time for the shock and has the option of adding additional resources from a specified time step and for the duration of the simulation. This is used in Chapter 6.

The Call parameters panel

Settings in this panel drive the input to the model and specify the desired output.

The timing for the simulation is determined here. *Number of time steps* is the time for which the model was run and can be set to any number. The user enters the number of calls in *Enter number of calls* and the *Call spacing* steps are automatically calculated. If the number of calls specified by the user exceed the calculated maximum, an error is flagged. The calls are distributed evenly throughout the specified *Number of time steps*.

The service level parameters are also defined in this panel. For this thesis the starting point for the urgent queue was 90% of calls answered in 10 steps and the non-urgent queue was 80% of calls answered in 27 steps and is dependent on the option chosen. These have been made variable so that changes to performance can be assessed at different service levels.

The 900 time step simulation panel

This is used to examine what is occurring within the 900 steps of a simulation run. It is used in conjunction with the CTA parameters panel and when selected, the CTA end time is set to be the same as the start time and the number of steps is set to 1. Within the number of time steps the output can be sampled at a range of user-selected intermediate steps.

The Call and CTA parameters panel

This panel is where the CTA parameters are set. It is used to demonstrate the effect on the performance of the model call centre by only varying one CTA parameter at a time. Provision was made for varying these between limits in defined steps. However, for this thesis only talk time is enabled as it has the greatest impact on the call handle time. Each of the enabled values in the panel can be set by the user.

The *call abandon time* is the time a call waits to be answered before abandoning.

The *Intercall Delay* is the mandatory time a CTA must wait before taking the next call. This is initially set to 10 steps and may be changed by the user.

The CTA call allocation method panel

Given that the NSWPAL CTI system allocates calls on a first-come-first-served basis this was emulated in the computer model with the longest waiting calls being serviced first. So, as in the real operational situation, the control of the performance is at the CTA management level.

Four methods of allocating calls to the model's CTAs using the CTA unique identifier were chosen. In this thesis, these identifiers are numerical and contiguous. The first allocation method, *Hierarchical* allocates calls from lowest to highest CTA identifier number. Where a CTA is busy, the next that is ready in the sequence is chosen. The next method is *Longest wait*. This is where the CTA waiting the longest time is allocated the next waiting call. Where more than one CTA has the same wait time, then a CTA is chosen at random from this group. There is a similar process for the *Shortest wait* option where the CTA waiting the shortest time is allocated the next waiting call. The final allocation method is *Random* where a CTA is selected at random from those waiting for a call.

The buttons panel

The *Clear figures* button removes the figures from the computer screen, the *Clear Cmd Window* button clears the command window, the *Reset* button clears all figures, clears the workspace, clears the command window and sets the model to the *Use test parameters* option. The *Start* button initialises the simulation and runs the model with the selected options and parameters.

4.6 Comparing the prototype and final models

A comparison of the prototype and final models under the same input conditions was performed to ensure the results were similar.

The results of this comparison were used to verify the final model. The inputs to the models for the comparison are shown in Table 4.3. It is important to note that this section does not examine the accuracy of the models against the NSWPAL data and is only a comparison between the models.

Each model was run for CTAs abandoning at 1,000 steps, 59 steps and 25 steps: the first abandon time was chosen to represent no calls abandoning since it it outside the number of steps for which the simulation was run, the second was chosen at random for calls that abandon after the acceptable waiting time, and the third was chosen for calls that abandon before the acceptable waiting time.

The models were run for 900 steps, corresponding to 15 minutes of real time. Calls were entered every 40 steps giving an expected number of calls of 22. The target service level was to answer 80% of the calls within 27 steps. Five CTAs were created to take the calls and each took seven steps to pick up the call, talked to the customers for a maximum of 360 steps, spent 60 steps in after-call work after the customer had hung up, and had a time between calls of 10 steps. The talk time was varied between 120 and 360 steps in steps of 20 for the three call abandon times.

The results of the simulations were plotted and presented in tabular form. In all of the result figures that follow, the legend terms SL2, SL3 and SL5 refer to Equations 2.2, 2.3 and 2.5.

Table 4.3: Input data for comparing the prototype and final models.

Queue:	Non-urgent
Service level AWT:	27 steps
Number of steps:	900, where 1 step is equivalent to 1 second
Inbound call spacing:	40 steps
The expected number of calls:	22
Number of CTAs:	5
CTA call pick up time:	7 steps
CTA talk time:	Varied from 120 to 360 in steps of 20 steps
CTA ACW time:	60 steps
CTA inter-call delay:	10 steps
Calls abandon times	1000, 59 or 25 steps
CTA call allocation method:	Hierarchical

The results of the prototype simulation can be seen in Figures 4.5 to 4.13. Figures 4.5 to 4.7 show the results for no abandoned calls, Figures 4.8 to 4.10 show the results for calls that abandon before the AWT at 25 steps and Figures 4.11 to 4.13 show the results for calls that abandon after the AWT at 59 steps.

Figures 4.14 to 4.22 show the final model results. Figures 4.14 to 4.16 show the results for no abandoned calls, Figures 4.17 to 4.19 show the results for calls that abandon before the AWT at 25 steps and Figures 4.20 to 4.22 show the results for calls that abandon after the AWT at 59 steps.

Although these figures show great similarity between the models, Table 4.4 gives more detail. The results for abandon times of 100 steps and 25 steps are identical. However, while the figures at an abandon time of 59 steps are similar, the results differ. The reason for this lies in the different ways the prototype and final models were implemented. The simple prototype model included the CTA states with the calls whereas the final model placed the CTA states with the CTAs. This is seen by referring back to Tables 4.1 and 4.2. Furthermore, the CTA methods provide detailed attention to the timing of the CTA states.

For both models, with all but the CTA talk time remaining constant over a run of the simulation, it was logical to expect that the service level would deteriorate at the higher levels of talk time. However, Figures 4.5 to 4.7 and 4.14 to 4.16 show that the service level rose after 160 steps. This occurred where abandoned calls were not included in the calculations and was due to the falling number of calls answered while the number of calls answered within the service level time did not change. This effect can be seen in Figure 4.23 which was the same for both models.

4.6.1 Prototype and final model performance at 59 steps abandon time

In both the prototype and final models, the service level revealed an oscillatory nature when calls abandoned at 59 steps as the CTA talk time is varied. This is

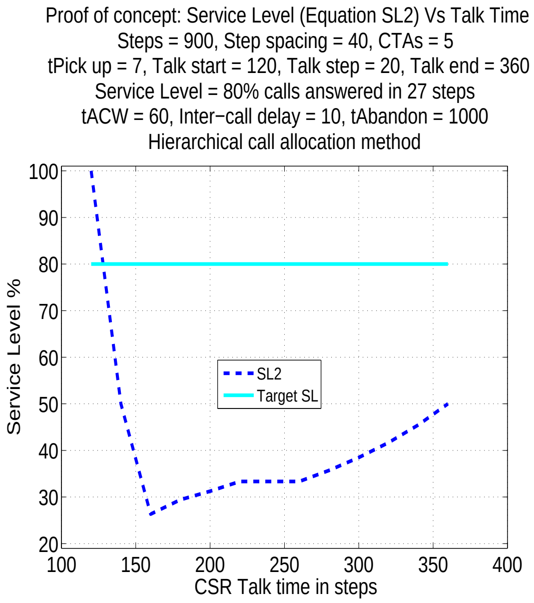

Figure 4.5: Prototype model results with no abandoned calls. Equation SL2.

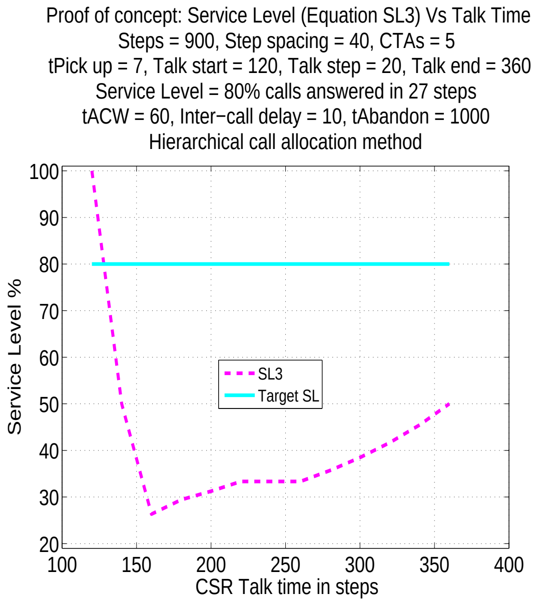

Figure 4.6: Prototype model results with no abandoned calls. Equation SL3.

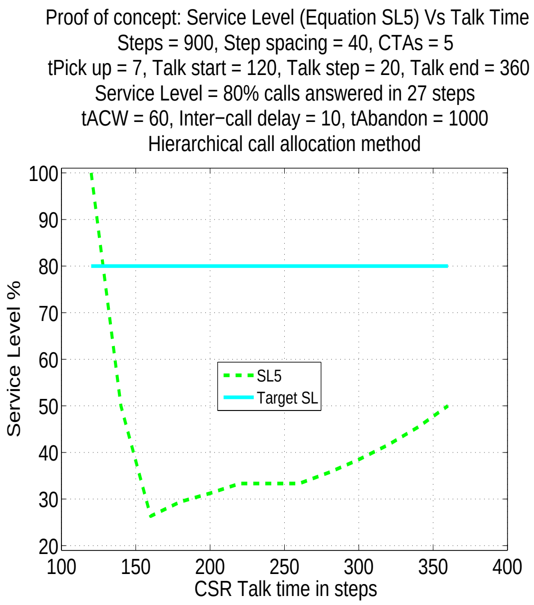

Figure 4.7: Prototype model results with no abandoned calls. Equation SL5.

For Equation SL2 see page 37.
For Equation SL3 see page 37.
For Equation SL5 see page 38.

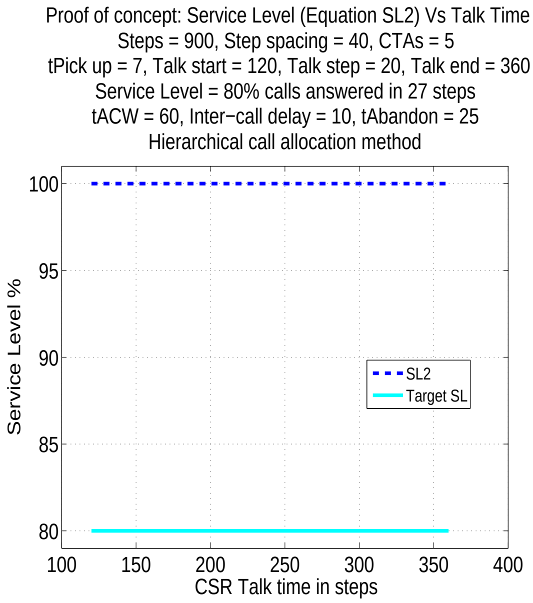

Figure 4.8: Prototype model results with calls abandoning at 25 steps. Equation SL2.

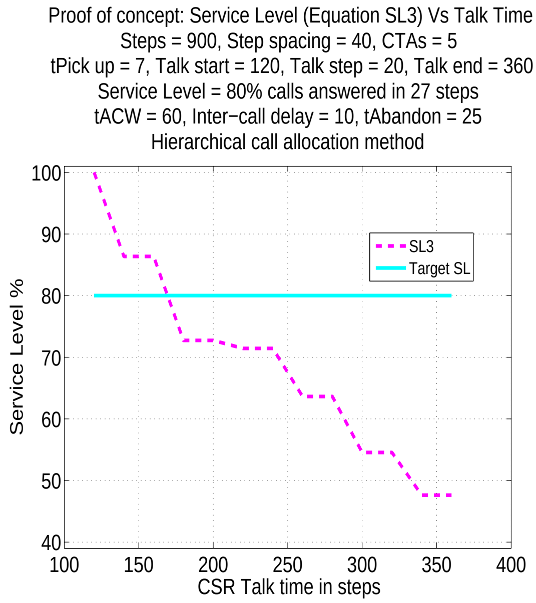

Figure 4.9: Prototype model results with calls abandoning at 25 steps. Equation SL3.

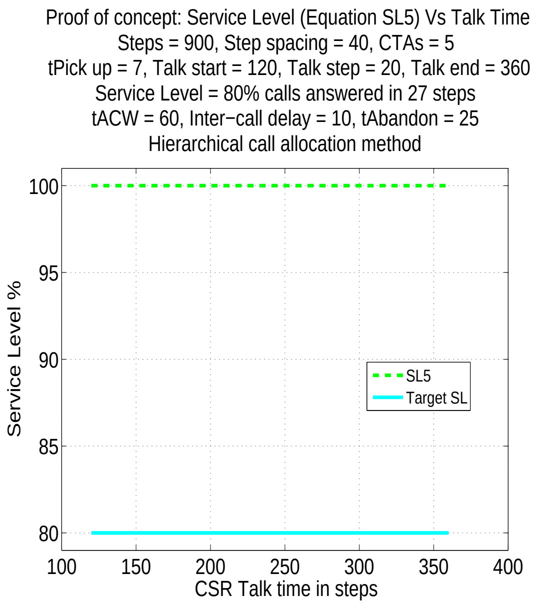

Figure 4.10: Prototype model results with calls abandoning at 25 steps. Equation SL5.

For Equation SL2 see page 37.
For Equation SL3 see page 37.
For Equation SL5 see page 38.

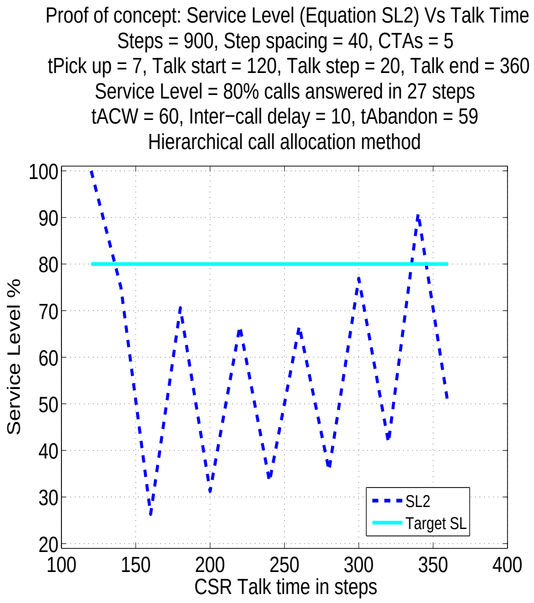

Figure 4.11: Prototype model results with calls abandoning at 59 steps. Equation SL2.

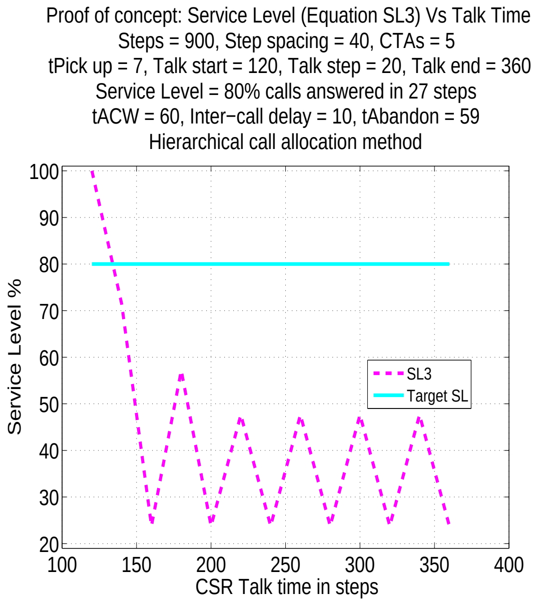

Figure 4.12: Prototype model results with calls abandoning at 59 steps. Equation SL3.

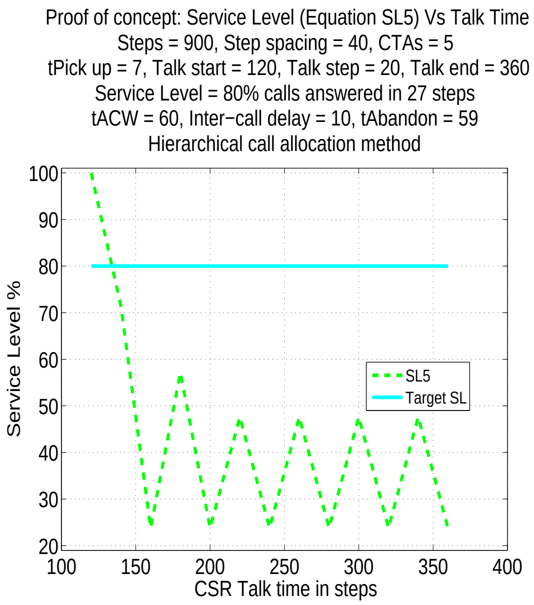

Figure 4.13: Prototype model results with calls abandoning at 59 steps. Equation SL5.

For Equation SL2 see page 37.
For Equation SL3 see page 37.
For Equation SL5 see page 38.

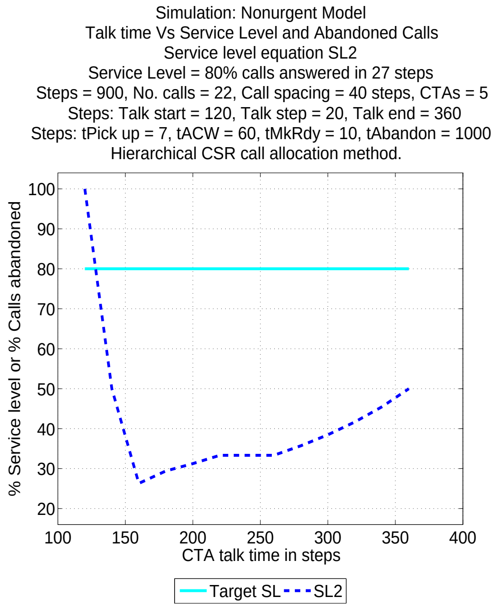

Figure 4.14: Simulation results with no abandoned calls. Equation SL2.

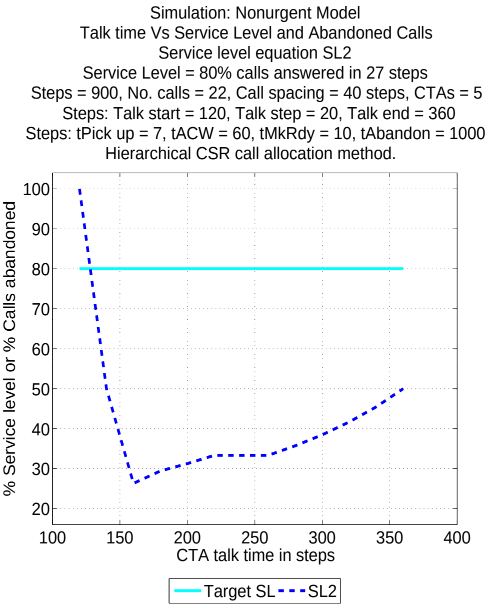

Figure 4.15: Simulation results with no abandoned calls. Equation SL3.

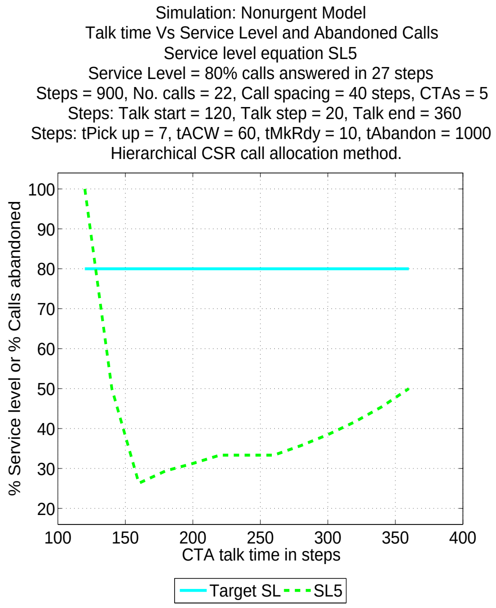

Figure 4.16: Simulation results with no abandoned calls. Equation SL5.

For Equation SL2 see page 37.
For Equation SL3 see page 37.
For Equation SL5 see page 38.

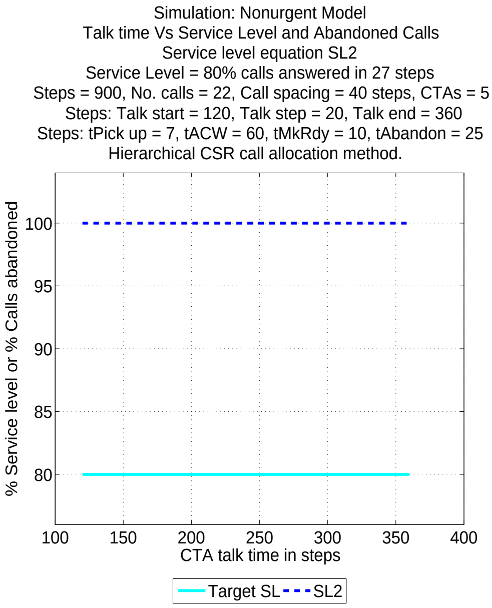

Figure 4.17: Simulation results with calls abandoning at 25 steps. Equation SL2.

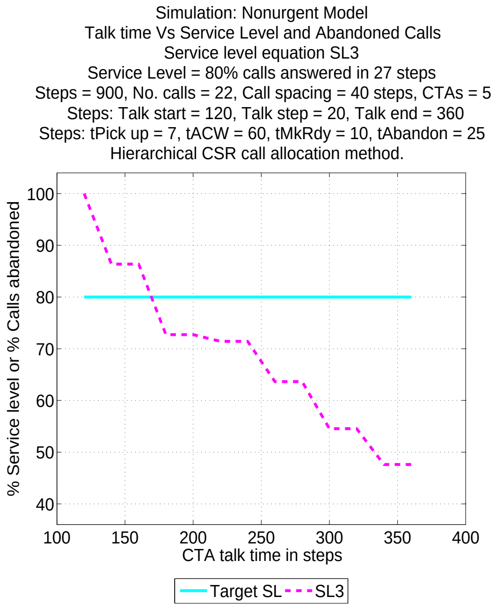

Figure 4.18: Simulation results with calls abandoning at 25 steps. Equation SL3.

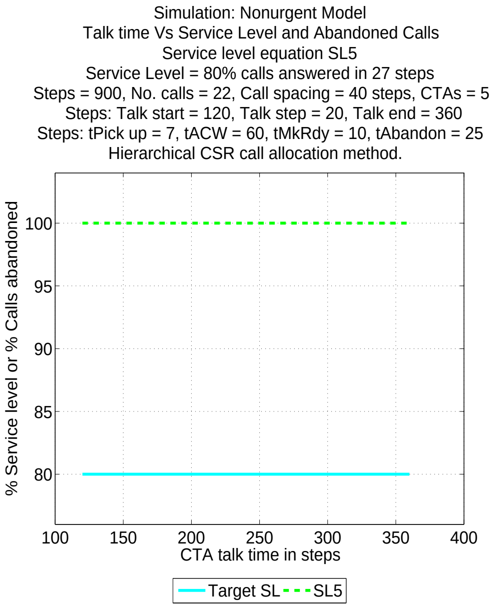

Figure 4.19: Simulation results with calls abandoning at 25 steps. Equation SL5.

For Equation SL2 see page 37.
For Equation SL2 see page 37.
For Equation SL2 see page 38.

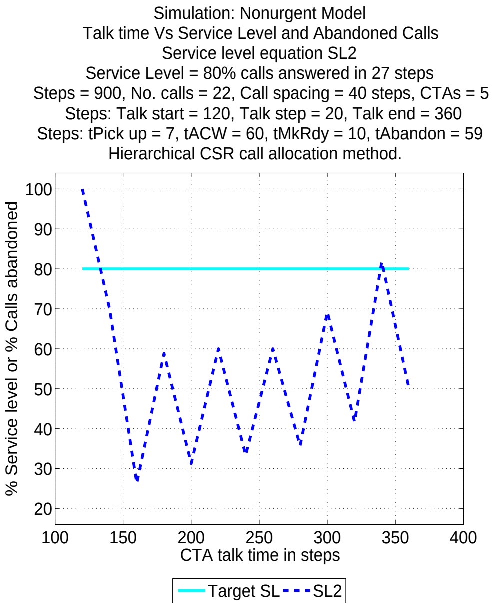

Figure 4.20: Simulation results with calls abandoning at 59 steps. Equation SL2.

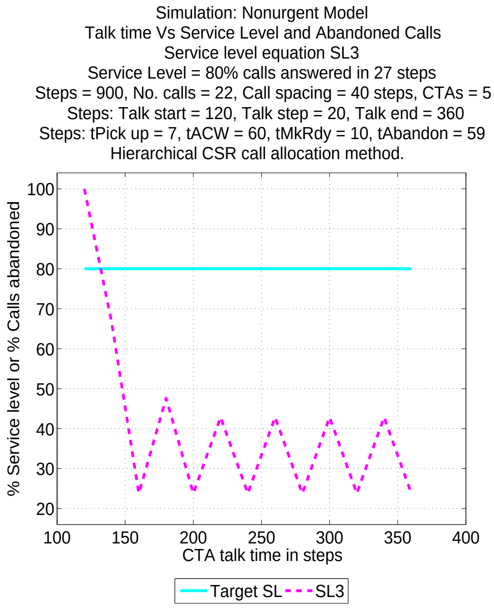

Figure 4.21: Simulation results with calls abandoning at 59 steps. Equation SL3.

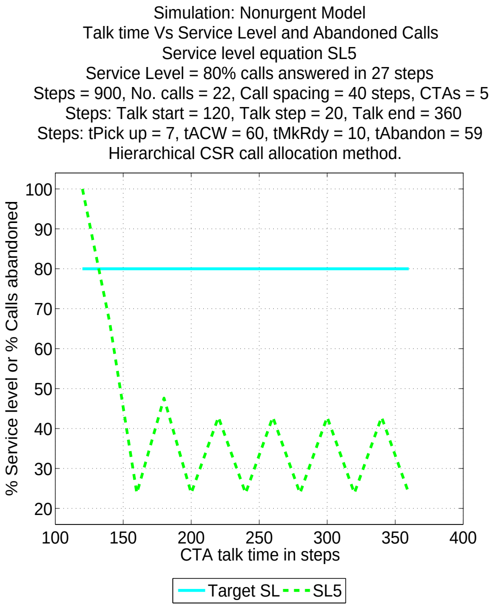

Figure 4.22: Simulation results with calls abandoning at 59 steps. Equation SL5.

For Equation SL2 see page 37.
For Equation SL2 see page 37.
For Equation SL2 see page 38.

Table 4.4: Prototype and final model service level results comparison using non-urgent parameters.

Talk time:	120	140	160	180	200	220	240	260	280	300	320	340	360
Abandon time: 1000 steps													
Prototype: Equation SL2:	100.0	50.0	26.3	29.4	31.2	33.3	33.3	33.3	35.7	38.5	41.7	45.5	50.0
Final: Equation SL2:	100.0	50.0	26.3	29.4	31.2	33.3	33.3	33.3	35.7	38.5	41.7	45.5	50.0
Prototype: Equation SL3:	100.0	50.0	26.3	29.4	31.2	33.3	33.3	33.3	35.7	38.5	41.7	45.5	50.0
Final: Equation SL3:	100.0	50.0	26.3	29.4	31.2	33.3	33.3	33.3	35.7	38.5	41.7	45.5	50.0
Prototype: Equation SL5:	100.0	50.0	26.3	29.4	31.2	33.3	33.3	33.3	35.7	38.5	41.7	45.5	50.0
Final: Equation SL5:	100.0	50.0	26.3	29.4	31.2	33.3	33.3	33.3	35.7	38.5	41.7	45.5	50.0
Abandon time: 59 steps													
Prototype: Equation SL2:	100.0	75.0	26.3	70.6	31.2	66.7	33.3	66.7	35.7	76.9	41.7	90.9	50.0
Final: Equation SL2:	100.0	70.0	26.3	58.8	31.2	60.0	33.3	60.0	35.7	69.2	41.7	81.8	50.0
Prototype: Equation SL3:	100.0	71.4	23.8	57.1	23.8	47.6	23.8	47.6	23.8	47.6	23.8	47.6	23.8
Final: Equation SL3:	100.0	66.7	23.8	47.6	23.8	42.9	23.8	42.9	23.8	42.9	23.8	42.9	23.8
Prototype: Equation SL5:	100.0	71.4	23.8	57.1	23.8	47.6	23.8	47.6	23.8	47.6	23.8	47.6	23.8
Final: Equation SL5:	100.0	66.7	23.8	47.6	23.8	42.9	23.8	42.9	23.8	42.9	23.8	42.9	23.8
Abandon time: 25 steps													
Prototype: Equation SL2:	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Final: Equation SL2:	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Prototype: Equation SL3:	100.0	86.4	86.4	72.7	72.7	71.4	71.4	63.6	63.6	54.5	54.5	47.6	47.6
Final: Equation SL3:	100.0	86.4	86.4	72.7	72.7	71.4	71.4	63.6	63.6	54.5	54.5	47.6	47.6
Prototype: Equation SL5:	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Final: Equation SL5:	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

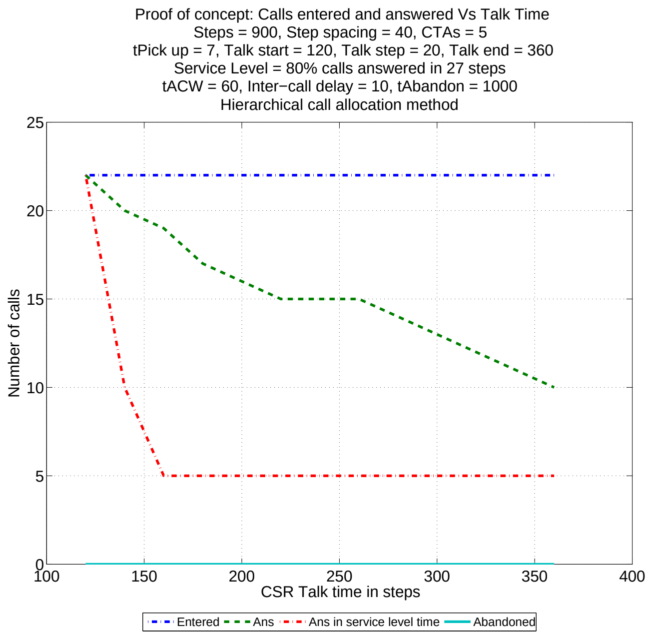

Figure 4.23: Prototype and final models' results with no abandoned calls. Calls entered, answered and abandoned.

shown in Figures 4.11 to 4.13 and 4.20 to 4.22 and is due to calls abandoning at the same time the CTA starts picking up the call.

The oscillatory nature is explained by referring to Table 4.5. Call 101 is serviced by CTA 711 and ends at step 287. CTA 711 then takes a mandatory 10 step break which means it will be ready to take the next call at step 298, the time step after the end of the break. In the meantime, call 106 was entered at time 240 and at step 298 has not been answered since CTAs 712 to 715 were on calls. So, at step 299, call 106 abandons, CTA 711 loses the call since it was in the call pick up state, stays in the ready state and services the next call 107. Due to all CTAs having the same talk time, this pattern repeats itself.

Table 4.5: Prototype and final model performance at 59 steps abandon time.
Non-urgent model call results for the following parameters ...
Service Level target = 80 percent of calls answered in 27 steps
CTA call allocation method: Hierarchical
Time steps = 900, Step spacing = 40 steps, Number of call takers = 5
Pickup time = 7, Talk time start = 180, Talk time end = 180, ACW time = 60, Inter-call delay time = 10
Abandon time = 59.

Call ID	Time call entered	Time call allocated	Time pick up ended	Time call answered	Time to answer call	Time talk ended	Time call ended	State	CTA ID	Time call abandoned	Time call waits to abandon
101	40	40	47	48	8	227	287	Finished	711	0	59
102	80	80	87	88	8	267	327	Finished	712	0	59
103	120	120	127	128	8	307	367	Finished	713	0	59
104	160	160	167	168	8	347	407	Finished	714	0	59
105	200	200	207	208	8	387	447	Finished	715	0	59
106	240	298	0	0	-1	0	0	Abandoned	711	299	59
107	280	300	307	308	28	487	547	Finished	711	0	59
108	320	338	345	346	26	525	585	Finished	712	0	59
109	360	378	385	386	26	565	625	Finished	713	0	59
110	400	418	425	426	26	605	665	Finished	714	0	59
111	440	458	465	466	26	645	705	Finished	715	0	59
112	480	0	0	0	-1	0	0	Abandoned	0	539	59
113	520	558	565	566	46	745	805	Finished	711	0	59
114	560	596	603	604	44	783	843	Finished	712	0	59
115	600	636	643	644	44	823	883	Finished	713	0	59
116	640	676	683	684	44	863	0	End talk	714	0	59
117	680	716	723	724	44	0	0	Talk	715	0	59
118	720	0	0	0	-1	0	0	Abandoned	0	779	59
119	760	816	0	0	-1	0	0	Abandoned	711	819	59
120	800	820	827	828	28	0	0	Talk	711	0	59
121	840	854	861	862	22	0	0	Talk	712	0	59
122	880	894	0	0	0	0	0	Pick up	713	0	59

4.7 Generating call streams from historical data

Since the NSWPAL business queue reports were presented as 15 minute summaries, there was a need to create a series of individual calls from this historical data. This section explains how this was achieved.

The historical call generator is invoked by the call centre graphical interface. It's function is to create individual calls within 15 minute time blocks which can be used to model and analyse the historical performance of the call centre. The historical call generator is capable of operating over a 24 hour period within any day of the week and uses the 15 minute blocks of the summary statistics as a basis for call generation. Within these 15 minute blocks, calls are created by generating the inter-call times. The minimum time between calls is one second. See Chapter 3 for an explanation of the data extraction process and Appendix A for the daily summary data. Where a specific date and time are required, these data can be obtained from the call centre daily management reports and put into the call centre model without using the historical input path.

Although calls can be generated over contiguous 15 minute periods up to 24 hours, it is best to model individual 15 minute blocks as call centre staffing can change between contiguous blocks.

Graphical interface

A graphical interface is used as a front end of the historical call generator to specify the parameters. This is shown in Figure 4.24, and consists of a series of drop-down blocks for error free data entry. Users can select either the urgent or non-urgent queue and a day of the week. The start and end hours can be selected from 00 hours to 23 hours and the start and end 15 minute blocks are selected from 00, 15, 30 or 45. The end time cannot precede the start time otherwise the user receives an error message. An SD multiplier allows a variation to the mean number of calls and the time multiplier allows calls to be generated in less than the 900 steps. Fixed and variable call spacing is facilitated and the user has the option of plotting the generated calls to the screen. The shock generator allows a multiple of the mean calls in a 15 minute block to be created to examine the call centre performance to an unexpected exogenous event under different call centre parameters and management scenarios. The resulting call stream data are stored in a workspace. This is read by the call centre ABM described in this thesis when its start button is clicked.

Creating historical calls

Calls may be created with a fixed or variable spacing. This option is selected from the historical graphical interface. Calls are created as a number of calls in one or more contiguous 15 minute blocks.

Where variable spacing is selected, the standard deviation of the 15 minute day of week summary is used to provide variability in the number of calls to be generated. This is in the form of a SD multiplier on the historical GUI and can be varied from zero to three steps in half step increments. Furthermore, when a single 15 minute simulation block is to be generated, the time scale can be compressed between 100 and 900 steps in steps of 100 to produce a high incoming call rate to simulate an unexpected event in the community.

The equation that underpins the historical call generator model is shown in Equation 4.1.

$$c_q(t) = \sum_{n=n_1}^{n_2} (g_q(t) + s_q(t)) \tag{4.1}$$

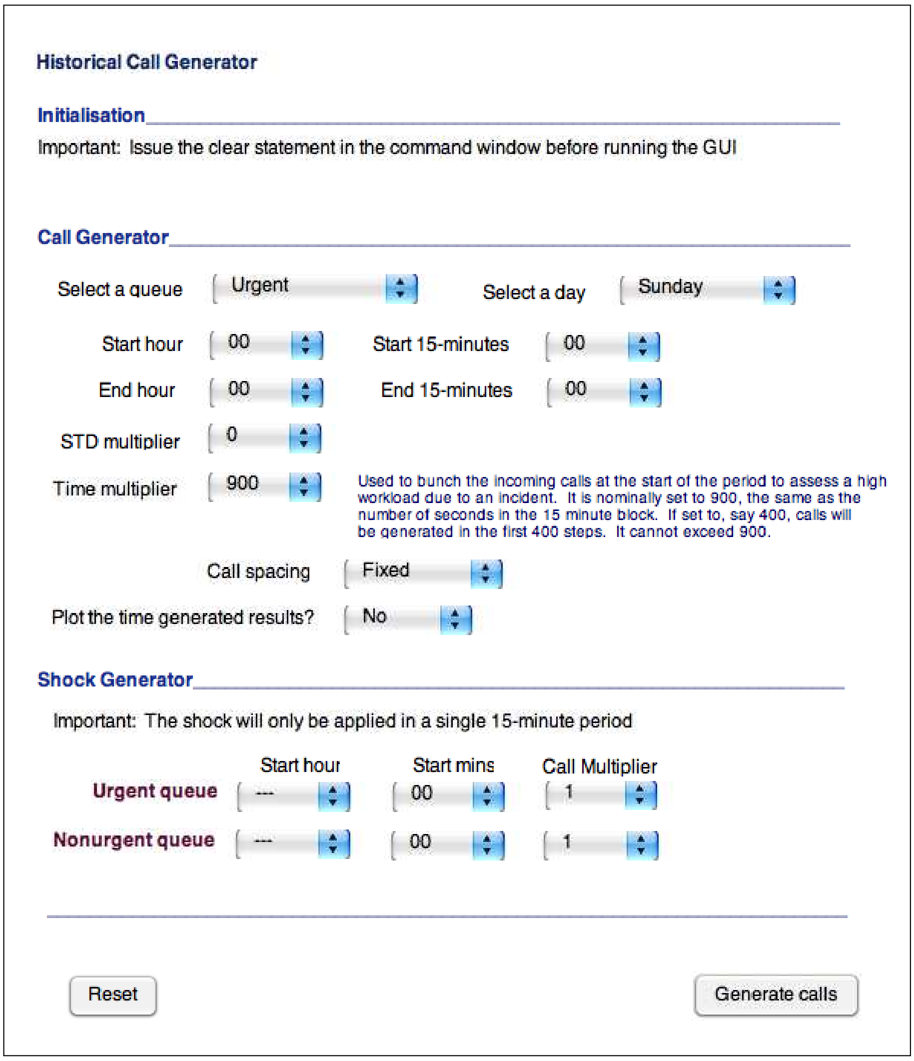

Figure 4.24: The historical data graphical interface.

where $c_q(t)$ is the call stream, $g_q(t)$ is the call stream derived from a day mean and SD, $s_q(t)$ is an exogenous shock, n is a range of 15 minute contiguous blocks within a 24-hour period on a single day and the subscript q is either the urgent or non-urgent queue.

The number of calls to be generated in a 15 minute block is calculated from the population $N(\mu_d, \sigma_d)$ where μ_d is the average number of calls in a 15 minute block, with σ_d being the SD. These calls need to be distributed through each 15 minute block. This is achieved by calculating the inter-call times from the population $900N(0,1)$ which is repeated for the number of calls to be generated. The factor of 900 is the number of seconds in a 15 minute period. These times are then sorted smallest to largest to produce a vector specifying where calls are to be created. If the calculated number of calls is negative, it is set to zero for the 15 minute period. This is realistic as the data shows that in quiet periods there may be no incoming calls on either or both of the queues. If the calculation indicates that multiple calls may be created at the same time, they are shifted by one second.

Depending on the type of call being taken, the time to service the call can vary. In the model, the call type is denoted by a level of difficulty.

For urgent calls, the aim is to despatch help to the caller as soon as possible. While the majority of urgent calls are dealt with expeditiously, there are from time-to-time calls such as those involving possible self harm on the part of the caller that can take a significant time that extend beyond the minimum time block of 15 minutes and involve one call taker. These are ignored since the interest is in assessing performance in the short term and so a single level of difficulty for the urgent calls is used. On the other hand there are a variety of calls received in the non-urgent queue and from anecdotal information these can be divided into four levels of difficulty. The level of difficulty is shown in the amplitude of the calls in the results that follow. Although these are part the historical call generator model, this option is not included in the final call centre model and may be undertaken as future work.

4.8 Chapter discussion and concluding remarks

In this chapter the process that led to the development of the final model was discussed. During this process, it was necessary to fine tune the operation of the prototype and final models to reach agreement in their performance.

In both the prototype and final models, it was possible to demonstrate the effect of including and not including customers who abandon a call queue before being answered. It was found that by not including abandoned calls, differences in the results from service levels calculations occurred. This conclusion agrees with Garnett et al. (2002) who state that effect of abandoning customers on service level should be considered in large call centres.

The model showed that although simple in concept, agent-based modelling was a successful technique for modelling an inbound emergency telephone call centre as all of the activities together with all of the necessary parameters associated with the calls and the people answering the calls were able to be included. This was achieved without the complexity of mathematical equations.

It was advantageous having two different models using different programming techniques to compare results. Had a single model been used, some of the finer timing relationships may have been missed. During completion of the final model, it was found that the results of the prototype and the results of the final models did not agree. Careful comparison of the changes in values and agent states at individual time steps in the test and simulation modes of operation for both models revealed the need for more CTA states. These were added to better monitor the progress of both the calls and the CTAs. These additional time milestones were then used to facilitate changes in state throughout the progress of a call. The overall result was a very high level of confidence that both models were operating correctly.

The next chapter deals with the calibration of the model against NSWPAL data where estimation of the call handle time, the call abandon time and the number of CTAs are discussed. A comparison on the model against the Erlang C model is also undertaken.

Chapter 5

CALIBRATION OF THE MODEL

5.1 Introduction

An important aspect of the model's construction was its calibration against NSWPAL data. A process was developed to implement this and it was demonstrated that the thesis model was a good approximation of the NSWPAL call centre.

The processes and results of the calibration of the call handle time and abandon time parameters are discussed as is a means for determining the number of CTAs. The latter was prepared and was compared against the Erlang C model, to demonstrate the differences in using the Erlang C model and a dynamic model.

The work in this chapter used the urgent queue option of the model and the NSWPAL Triple Zero (000) data. Since the NSWPAL uses Equation 2.2 to calculate its service level it was used in the programs written for this chapter.

5.2 Estimating the call handle time from NSWPAL data

NSWPAL Triple Zero (000) queue data from January 2008 to February 2008 inclusive were analysed and plotted to determine the mean, median, SD and spread of the average inbound talk time, average ACW and average AHT. The sample size was 81,596 inbound calls to the Triple Zero (000) queue and the calls involved 147 CSRs.

The summary statistics can be seen in Table 5.1 and the results are shown in Figures 5.1 to 5.3. The average inbound talk time distribution was found to be near normal in shape and the other two distributions were slightly skewed to the left. The results of the experiments in the next chapter used the means for the inbound talk time and ACW as starting points.

For sensitivity testing, Figures 5.1 and 5.2 can be used as a guide with the inbound talk time being in the range 100 steps to 180 steps and the ACW in the range 125 steps to 225 steps.

Table 5.1: NSWPAL Triple Zero (000) queue summary statistics for January 2008 to February 2008.

Sample size: 81,596			
Metric	Mean (seconds)	Median (seconds)	SD (seconds)
Average inbound talk time :	141	141	33
Average ACW time:	184	171	69
Average handle time:	325	314	84

5.3 *Determining the number of CTAs for the model*

Since the NSWPAL queue reports did not contain the number of CSRs taking calls, it was necessary to determine these in order to use the model. This section describes the process used to develop a method for determining the unknown number of CSRs which was required for calibrating the model against the NSWPAL data.

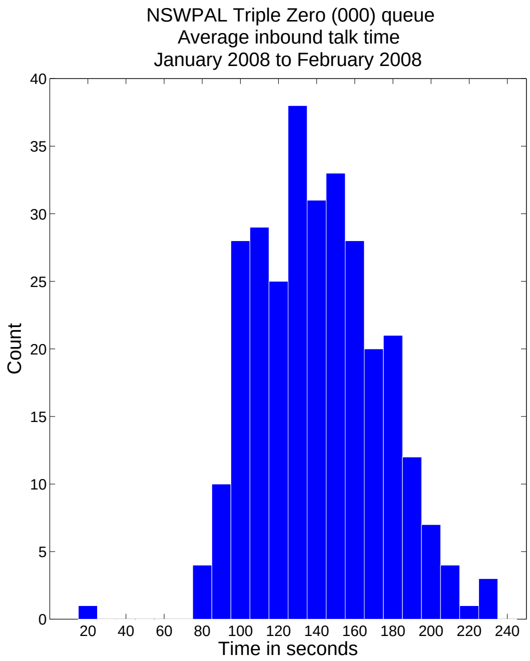

Figure 5.1: Triple Zero (000)
January 2008 - February 2008
Average inbound talk time.

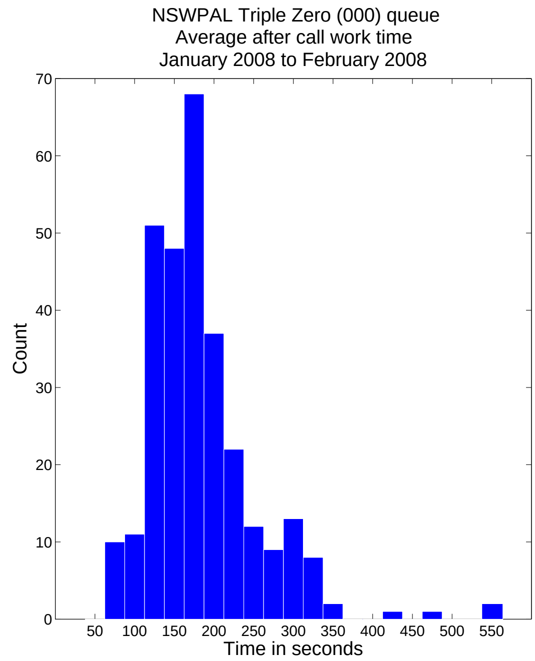

Figure 5.2: Triple Zero (000)
January 2008 - February 2008
Average ACW.

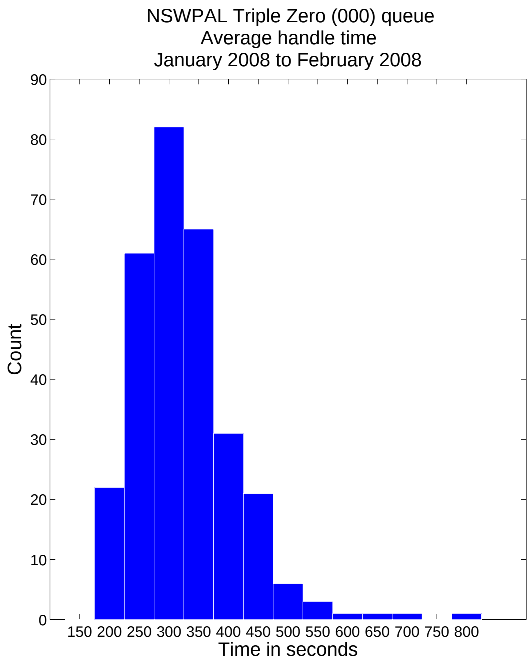

Figure 5.3: Triple Zero (000)
January 2008 - February 2008
AHT.

A program using the Erlang C model[1] was written by the researcher to find the number of CTAs given a target service level, the AWT, the inbound call rate and the call handle time. This program incremented the number of CTAs from 1 in steps of 1 and at each step the service level was calculated. The program continued while the calculated service level was less than the desired service level whence it stopped. The end result was the number of CTAs.

The program developed here provided results that agreed with an on-line calculator found in the literature[2] (Koole, 2007). It produced the same number of CTAs as the on-line calculator for the same input values. Table 5.2 shows the inputs to the calculators and Table 5.3 shows the results. These results were used later to calibrate the thesis model.

Table 5.2: Input data to the two programs based on the Erlang C model calculating the numbers of CSRs.

Service level:	90% calls answered in 10 steps
Number of calls in 15 minutes:	Varied from 1 to 90. See Table 5.3
Call handle time:	325 steps

Table 5.3: Number of CTAs calculated from the Erlang C-based programs.

Number of calls in 15 minutes:	1	5	10	20	30	40	50	60	70	80	90
CTAs, researcher program:	2	5	7	12	16	21	25	29	33	37	41
CTAs, Koole (2007) program:	2	5	7	12	16	21	25	29	33	37	41

5.4 Comparing the thesis model against the Erlang C model

The Erlang C model can be used in almost any queueing situation (Cleveland and Mayben, 2001). It is used 'to estimate the stationary performance of a system for

[1] See Equations 2.8 to 2.13 on p. 41
[2] See `http://www.math.vu.nl/~koole/ccmath/ErlangC/index.php`

short intervals' (Gans et al., 2003). Its use in the call centre industry is to determine queue staffing requirements since it easy to use (Cleveland and Mayben, 2001, Gans et al., 2003, Barber and Durr, 2004, Mandelbaum and Hlynka, 2008). The Erlang C model, however, is seen as being an over-simplification since it ignores abandonment, busying out or caller retries (Gans et al., 2003).

Gans et al. (2003) state that, due to approximations associated with the Erlang C model's underlying assumptions, 'Erlang-C-based predictions can also turn out highly inaccurate' (Gans et al., 2003, pp.22-23).

A comparison of the model developed here with the Erlang C model was undertaken to determine the number of CTAs required for similar model inputs. The inputs to the Erlang C model are shown in Table 5.2 and those to the thesis model are shown in Table 5.4. The longest waiting CTA call allocation method was used since this is the method used at the NSWPAL. The model developed here was set not to include abandonment since this is not included in the Erlang C model (Gans et al., 2003, Mandelbaum and Zeltyn, 2007, Franzese et al., 2009).

Table 5.4: The input data for comparing the thesis model against the Erlang C model in determining the number of CTAs.

Queue:	Urgent
Service level:	90% calls answered in 10 steps
Number of steps:	900, where 1 step is equivalent to 1 second
The expected number of calls:	Varied from 1 to 90. See Table 5.3
CTA call pick up time:	7 steps
CTA talk time:	141 steps and 100 steps
CTA ACW time:	184 steps and 125 steps
Call handle time:	325 steps and 225 steps
CTA inter-call delay:	10 steps
Calls abandon time:	1000 steps for no abandoning
CTA call allocation method:	Longest waiting CTA

For the comparison, it was necessary to vary the expected number of calls from 1 and not 0 in the model since, when Equations 2.2 and 2.5 are used to calculate the service levels, the results are indeterminate when there are no calls[3].

Two sets of results are shown in Figure 5.4. The first is for a service time of 325 steps and the second is for 225 steps. Referring to the results for 325 step service time, a difference can be seen between the model and the Erlang C model with the latter producing a greater number of resources. A linear equation to approximate the results using a standard least squares curve fitting routine was considered, however, there were too many different possibilities for the inputs and this was impractical. To show this, a second plot was prepared with a different service time of 225 steps, resulting in a change in gradient.

The outcome of these experiment suggests that the Erlang C model can be used to estimate the number of CTAs for the thesis model. However, due to the differences in results between models, the Erlang C model only provides a good place to start in determining staffing.

The two models have significant differences. The thesis model is deterministic since it uses homogeneous CTAs and calls, only works in integer numbers, has a constant arrival rate based on the number of inbound calls. On the other hand, the Erlang C model does not take the progress of time or the contribution of the individual call takers into account.

5.5 Calibrating the model

To run the model it was important that the number of CTAs, the call handle time and the call abandon time were known. This section describes the process under-

[3] The division becomes $zero/zero$

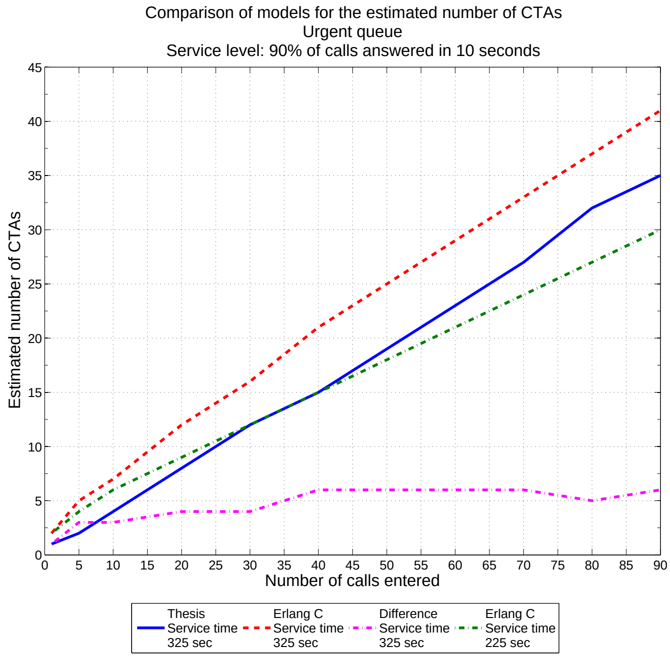

Figure 5.4: Comparing the different ways the number of CTAs is determined.

taken to check the calibration of the model against NSWPAL data using the call handle time.

To determine the accuracy of the model with respect to service level and call handle time, the model was calibrated by comparing the number of CTAs as determined by the model against the number of CSRs scheduled to work in the period 6 pm on 6 July 2007 to 6 am on 7 July 2007. This was achieved by varying the call handle time. These resulting call handle times were then compared statistically against NSWPAL call handle data. Table 5.7 shows the summary statistics for these call handle time data. An alternate front-end to the model was written to determine of the number of CTAs and the resulting call handle time.

Data for the number of CSRs scheduled to work were available for the period 6 pm on 6 July 2007 to 6 am on 7 July 2007 and are shown in the sixth column of Table 5.6. These, together with data in Tables 5.1 and 5.7 were used for the calibration. The inputs to the model were the number of calls entered and the resulting service level from the queue report, and a range of call handle times. The constants were the number of steps over which the simulation was run, the inter-call delay, the call pickup time, the call abandon time, and the CTA call allocation method.

For a given number of calls entered and the corresponding service level, the call handle time was varied with the values in Table 5.1 being used as a starting point. At each call handle time value, the number of CTAs was incremented by the program from an initial value of 1 and continued while the service level at each step was less than the service level in the NSWPAL data. At the end of each CTA increment, the number of CTAs corresponding the service level that was closest to the NSWPAL data was chosen.

Table 5.5 shows the general input data used and Table 5.6 shows the NSWPAL data used from Appendix B.1. Table 5.6 also shows the results for the estimated number of CSRs and the call handle time at which this was achieved. The accuracy of the latter is within 5 time steps.

Table 5.5: Input data to the researcher's model to estimate the number of CTAs.

Queue:	Urgent
Service level:	90% calls answered in 10 steps
Service level equation:	Equation 2.2
Number of steps:	900 to simulate a 15 minute period
Number of calls entered:	Varies with time slot. See Table 5.6
Calls' abandon time:	1000 steps so that no calls abandon
CTA call pick up time:	7 steps
CTA Call handle time:	Varied by the researcher
CTA inter-call delay:	10 steps
CTA call allocation method:	Longest waiting CTA

Table 5.6: Input data and results calibration to estimate the call handle time.

	NSWPAL data					Model results	
Row index	Date July 2007	Time (hh:mm)	No. of calls entered	Service level %	No. of scheduled CSRs	Estimated number of CTAs	Handle time (steps)
R1	6	18:00 - 18:15	31	50	15	15	405
R2	6	18:15 - 18:30	28	88	15	15	420
R3	6	18:30 - 18:45	31	94	15	15	380
R4	6	18:45 - 19:00	28	93	15	15	420
R5	6	19:00 - 19:15	25	100	17	17	550
R6	6	19:15 - 19:30	22	100	17	17	610
R7	6	19:30 - 19:45	27	100	17	17	500
R8	6	19:45 - 20:00	30	97	17	17	450
R9	6	20:00 - 20:15	34	74	15	15	350
R10	6	20:15 - 20:30	32	91	15	15	365
R11	6	20:30 - 20:45	46	100	15	15	250
R12	6	20:45 - 21:00	27	100	15	15	435
R13	6	21:00 - 21:15	35	97	16	16	360
R14	6	21:15 - 21:30	25	100	16	16	510
R15	6	21:30 - 21:45	33	100	16	16	375
R16	6	21:45 - 22:00	40	91	16	16	325
R17	6	22:00 - 22:15	34	55	16	16	390
R18	6	22:15 - 22:30	39	60	16	16	360
R19	6	22:30 - 22:45	37	70	16	16	370
R20	6	22:45 - 23:00	66	0	16	No result	No result
R21	6	23:00 - 23:15	75	0	17	No result	No result
R22	6	23:15 - 23:30	79	0	17	No result	No result
R23	6	23:30 - 23:45	54	50	17	17	260
R24	6	23:45 - 00:00	38	88	17	17	360
R25	7	00:00 - 00:15	56	12	17	6	81

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Table 5.6 – continued from previous page

	NSWPAL data					Model results	
Row index	Date July 2007	Time (hh:mm)	No. of calls entered	Service level %	No. of scheduled CSRs	Estimated number of CTAs	Call handle time (steps)
R26	7	00:15 - 00:30	45	0	17	No result	No result
R27	7	00:30 - 00:45	31	78	17	17	435
R28	7	00:45 - 01:00	38	59	17	17	385
R29	7	01:00 - 01:15	34	43	12	12	300
R30	7	01:15 - 01:30	33	76	12	12	275
R31	7	01:30 - 01:45	37	50	12	12	275
R32	7	01:45 - 02:00	16	100	12	12	570
R33	7	02:00 - 02:15	17	88	8	8	340
R34	7	02:15 - 02:30	16	86	8	8	360
R35	7	02:30 - 02:45	24	62	8	8	275
R36	7	02:45 - 03:00	20	38	8	6	250
R37	7	03:00 - 03:15	32	100	7	7	145
R38	7	03:15 - 03:30	30	43	7	7	190
R39	7	03:30 - 03:45	23	56	7	7	250
R40	7	03:45 - 04:00	13	92	7	7	270
R41	7	04:00 - 04:15	17	69	5	5	190
R42	7	04:15 - 04:30	9	100	5	5	350
R43	7	04:30 - 04:45	17	94	5	5	190
R44	7	04:45 - 05:00	17	73	5	5	225
R45	7	05:00 - 05:15	21	67	7	7	235
R46	7	05:15 - 05:30	11	100	7	7	435
R47	7	05:30 - 05:45	3	100	7	3	435
R48	7	05:45 - 06:00	5	100	7	5	590

Referring now to Table 5.6, it was not always possible to match the service levels. This can be seen in rows 20 to 22, 25, 26, 36, 47 and 48 which are shaded grey. In the case of rows 20 to 22 and 26 it was not possible to run the model with zero service level. In rows 25, 36, 47 and 48, the estimated number of CTAs was less than the number scheduled. In these cases, although the number of CSRs scheduled were known, it was not known how many were logged in to take the calls. At these times, CSRs may have been logged out due to meal breaks, scheduled breaks, stress or, they may have not attended work because of illness or other personal reasons. Removing these data from any further analysis gave a sample size of 40. Table 5.7 shows the summary statistics for the call handle time.

Table 5.7: NSWPAL Triple Zero (000) queue call handle time summary for 6 pm 6 July 2007 to 6 am 7 July 2007.

Metric	Mean (seconds)	Median (seconds)	SD (seconds)	Sample size
Call handle time:	353	358	108	40

A difference of means test (Rumsey, 2003, Freund, 1971) was used to determine whether the call handle time as determined by the model was equal to the call handle time determined by analysing NSWPAL data. The latter is described in Section 5.2. To determine the difference between two means, Equation 5.1 (Freund, 1971, p.319) was used. Here, z is the standard score test statistic, $\overline{x_1}$ and $\overline{x_2}$ are the sample means, n_1 and n_2 are the sample sizes, σ_1^2 and σ_2^2 are the sample variances and δ is a constant.

$$z = \frac{\overline{x_1} - \overline{x_2} - \delta}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_1^2}{n_2}}} \tag{5.1}$$

The null hypothesis was that the sample averages are equal giving $H_0 : \mu_1 - \mu_2 = 0$ and $\delta = 0$.

The formula and values in Table 5.8 give the resulting standard score, $z = 1.63$ calls and the normal cumulative distribution value or p-value of 0.949 calls. Based on these figures, the null hypothesis was accepted indicating that the thesis model was a good approximation of the NSWPAL call centre. It was observed however that in both cases the SDs were large compared to the sample means, giving a broad distribution call handle times.

Table 5.8: Data comparing the sample call handle time averages in seconds.

	6-7 July 2007	Jan-Feb 2008
Sample size:	40	81,596
Mean:	353	325
Variance:	11,678	7,056
SD:	108	84

5.6 Estimating the call abandon time

Another important input parameter for the model is the call abandon time. Since the NSWPAL daily queue reports included only the maximum times to abandon and not the averages, it was necessary for the researcher to estimate possible values to be used when using the model. An examination of the distribution of abandon times was undertaken, followed by a comparison of the summary statistics.

Initially the period 6 pm 6 July 2007 to 6 am 7 July 2007 was analysed as this followed logically from the previous Section 5.5. This contained the maximum call abandon times. The results are shown in Figure 5.5. A visual inspection revealed a small group of maximum abandon times in the range 40 to 80 seconds and a group at greater than 110 seconds.

Due to the small sample size, the whole month of July 2007 was examined giving similar results with greater detail. This is shown in Figure 5.6. Knowing that July 2007 had a disruptive exogenous event, the researcher analysed three additional months; May 2008, August 2008 and December 2008. The first two were chosen since they were in the colder part of the year in the southern hemisphere with shorter daylight hour periods and less likelihood of public disturbances and antisocial behaviour. December 2008 was chosen as it was a summer month with longer daylight hours and was the main extended holiday period in New South Wales, Australia. The four months gave a total data set of 11,904 samples.

All months exhibited the same 3 groupings: 0 to 10 seconds, 40 to 80 seconds, and greater that 80 seconds. This can be seen in Figures 5.6 to 5.9.

A statistical summary was prepared for each of these months and the period from 6 pm 6 July 2007 to 6 am 7 July 2007. In each case abandoned calls in the range 0 to 10 seconds were not analysed as these were within the AWT of 10 seconds for the Triple Zero (000) queue. It was reasonable to assume that those who abandoned within 10 seconds have either dialled incorrectly or changed their mind. Table 5.9 shows the results for mid-range maximum abandon times from 40 seconds to less than or equal to 80 seconds. Table 5.10 shows the results for high-range maximum abandon times greater than 80 seconds.

The mid-range maximum abandon times for July 2007, May 2008, August 2008 and December 2008 in Rows 2 to 5 in Table 5.9 show that although the sample sizes varied from 325 to 766, the mean maximum abandon over the 4 months was 51 seconds and the mode was 46 seconds. Similar means and similar SDs indicated that the individual months were statistically similar and could be used as a basis for estimating the abandon time in the model. Due to the distributions not being normal in shape, the mode value of 46 seconds (program steps) was chosen as a starting point for abandon time in the model.

A similar analysis was undertaken for the high-range maximum abandon times. The results are shown in Table 5.10. These can be used when analysing the effect of very patient customers. Row 1 shows the period 6 pm 6 July 2007 to 6 am 7 July 2007 where there are a greater number of call waiting than in the mid-range for the same period. Since an unexpected exogenous event during that period[4] had an impact on the public, the callers may have been willing to wait longer.

This event had an effect on the July monthly summary statistics, as shown when comparing Row 2 in Table 5.10 with Rows 3 to 5. Although the sample sizes were similar, the July figures far exceeded those of the other 3 months.

Considering May 2008, August 2008 and December 2008, Rows 3 to 5 in Table 5.10, the mean high-range maximum abandon times were almost equal and had an average of 88.5 seconds. The SDs were very small and each of the 3 months had equal modes of 89 seconds. These indicated that the of May 2008, August 2008 and December 2008 months were statistically similar and could be used as a basis for estimating the high-range abandon times in the model. The mode value of 89 seconds (steps) can be used for the high-range abandon times in the model.

5.7 Chapter concluding remarks

The NSWPAL daily queue reports did not include the AHT for the calls in the 15 minute periods, the number of CSRs logged in to take calls or the average abandon time and so it was necessary to find values for these parameters.

[4] See Section 3.5 on p.63 for an explanation of the event.

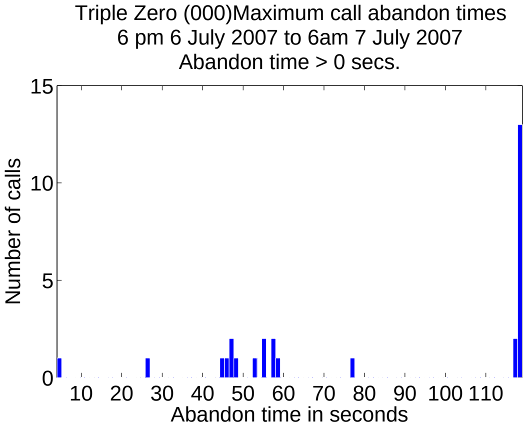


Figure 5.5: Triple Zero (000)
6 pm 6 July to 6 am 7 July 2007
maximum abandon times.

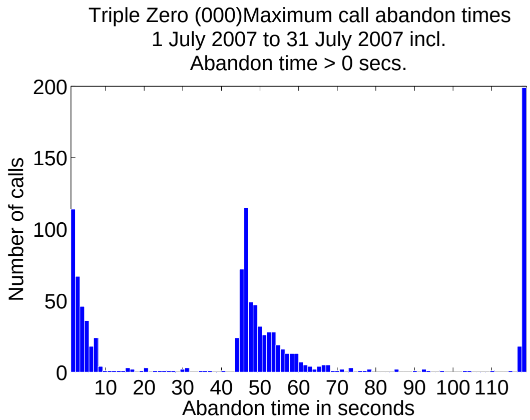


Figure 5.6: Triple Zero (000)
1 July 2007 to 31 July 2007
maximum abandon times.

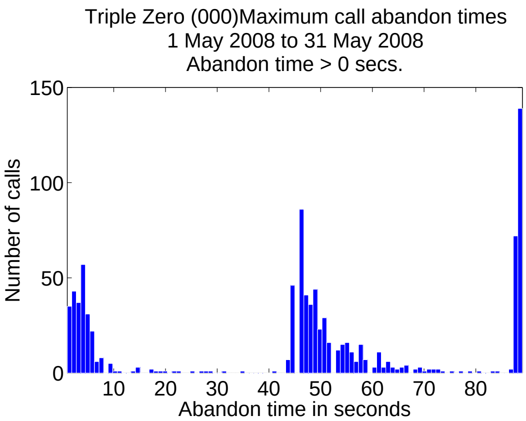


Figure 5.7: Triple Zero (000)
1 May 2008 to 31 May 2008
maximum abandon times.

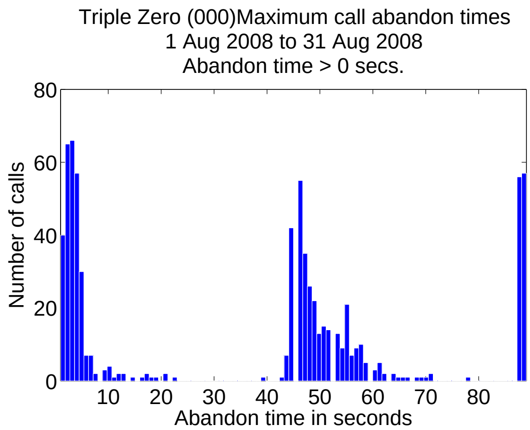


Figure 5.8: Triple Zero (000)
1 August 2007 to 31 August
2007 maximum abandon times.

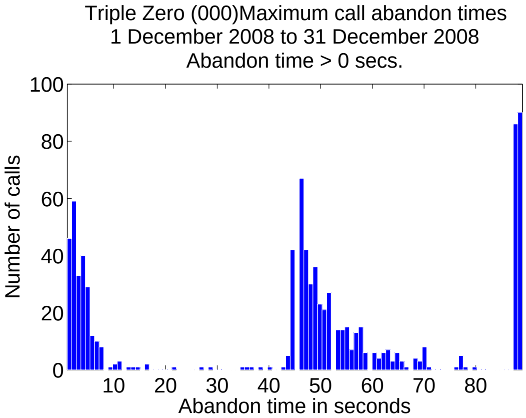


Figure 5.9: Triple Zero (000)
1 December 2008 to 31 December
2008 maximum abandon times.

In Section 5.2, the call handle time and summary statistics were prepared from AHT data obtained for two contiguous months and are shown in Table 5.1. These results were used to calibrate the thesis model.

Given a target service level, the AWT, the inbound call rate and the call handle time, the number of CTAs was determined based on the Erlang C model. They were compared successfully with the results of an on-line calculator found in the literature for the same input values. This is described in Section 5.3.

Comparison of the model described here against the Erlang C model was undertaken to determine the number of CTAs for the same input data. This is described in Section 5.4 and the difference between the stationary results of the Erlang C model and the results from the dynamic model was demonstrated.

In Section 5.5 the results of calibrating the thesis model against known NSWPAL data was undertaken. This analysis indicated that the thesis model was able to approximate the NSWPAL call centre.

In the absence of average abandon time data, the maximum call abandon time data from four non-contiguous months were used to estimate the abandon times to be used in applying the model. This is described in Section 5.6

In the next chapter, the attributes of the model are demonstrated and the call allocation methods are tested.

Table 5.9: Results for the analysis of maximum abandon times in the range 40 to 80 seconds.

Row index	Date/Time	Sample size	Min	Max	Range	Mean	Median	SD	Mode
					- All in seconds -				
Row 1	6 pm 6 Jul 2007 to 6am 7 Jul 2007	12	45	64	19	51.2	47.0	8.0	45.0
Row 2	1 Jul 2007 to 31 Jul 2007	766	44	78	34	50.6	49.0	6.3	45.0
Row 3	1 May 2008 to 31 May 2008	462	41	79	38	51.0	49.0	6.6	46.0
Row 4	1 Aug 2008 to 31 Aug 2008	325	43	78	35	50.3	48.0	5.6	46.0
Row 5	1 Dec 2008 to 31 Dec 2008	438	43	80	37	51.9	49.0	7.2	46.0

Table 5.10: Results for the analysis of maximum abandon times greater than 80 seconds.

Row index	Date/Time	Sample size	Min	Max	Range	Mean	Median	SD	Mode
					- All in seconds -				
Row 1	6 pm 6 Jul 2007 to 6am 7 Jul 2007	15	117	119	2	118.0	118.0	0.5	118.0
Row 2	1 Jul 2007 to 31 Jul 2007	218	115	119	4	118.1	118.0	0.6	118.0
Row 3	1 May 2008 to 31 May 2008	216	81	89	8	88.6	89	0.9	89.0
Row 4	1 Aug 2008 to 31 Aug 2008	113	88	89	1	88.5	89	0.5	89.0
Row 5	1 Dec 2008 to 31 Dec 2008	176	88	89	1	88.5	89.0	0.5	89.0

Chapter 6

APPLYING THE MODEL

6.1 Introduction

In this chapter a series of experiments is described that demonstrate the capabilities of the model. Since this thesis is focussed on emergency services call centres such as NSWPAL, the urgent queue component of the model was used as a basis for these experiments.

The following experiments were undertaken:

- Experiment 1: Service level calculation anomaly.
- Experiment 2: The effect of talk time on service level.
- Experiment 3: The response of the model to a sudden increase in calls.
- Experiment 4: Improving the service level following a sudden increase in calls.
- Experiment 5: Different methods of allocating calls to CTAs.
- Experiment 6: Service level anomaly at the start of day.
- Experiment 7: Using historical data to assess performance.
- Experiment 8: Comparing the thesis and Erlang C models

In each of these experiments, the output metric of interest was the service level. Service level equations 2.2 and 2.5 were used to highlight the difference between not including and including abandoned calls in the calculations. Equation 2.2 does not include abandoned calls and Equation 2.5 does include abandoned calls. This was discussed in Section 2.3.2 on page 36. In this chapter, these equations are also referred to as SL2 and SL5 respectively in figures and section headings. For Equation SL2 see page 37 and for Equation SL5 see page 38 of this thesis.

6.2 Experiment 1: Service level calculation anomaly between equations SL2 and SL5

In Section 2.3.2 the different methods of calculating service level were discussed. There it was explained that the effect of abandoned call on service level must be considered to reveal the customer's perception of service quality (Garnett et al., 2002, Koole, 2007). However since there are no formal standards, the method of calculating service level is left to the individual call centre managers.

This experiment shows the difference between including and not including abandoned calls in the service level calculation using Equations 2.2 and 2.5.

The values in Table 6.1 were used as inputs to the model. The model was run for 900 steps, corresponding to 15 minutes. Values for the talk time, ACW time and call abandon time were taken from those determined in Chapter 5. The model was purposely run under-staffed to ensure abandoning.

Figure 6.1 shows the results of the simulation when Equations 2.2 and 2.5 were used to calculate the service level. When using Equation 2.2 the service level result was higher than Equation 2.5. For the first 190 steps, both equations gave a service level of 100%. From that point, the abandon rate increased. While both equations contain the total number of calls answered, the denominator in Equation 2.5 increased with the number of calls abandoning. This resulted in the service level as calculated by Equation 2.5 falling.

Table 6.1: Experiment 1 input data.

Queue:	Urgent
Service level target:	90% calls answered within10 steps
Simulation period:	900 steps
Number of inbound calls:	20
Inbound call spacing:	43 steps
Number of CTAs:	3
Pick up time:	7 steps
Talk time:	141 steps
ACW time:	184 steps
Abandon time:	46 steps
Make ready/inter-call delay time:	10 steps
CTA call allocation method:	Longest waiting CTA

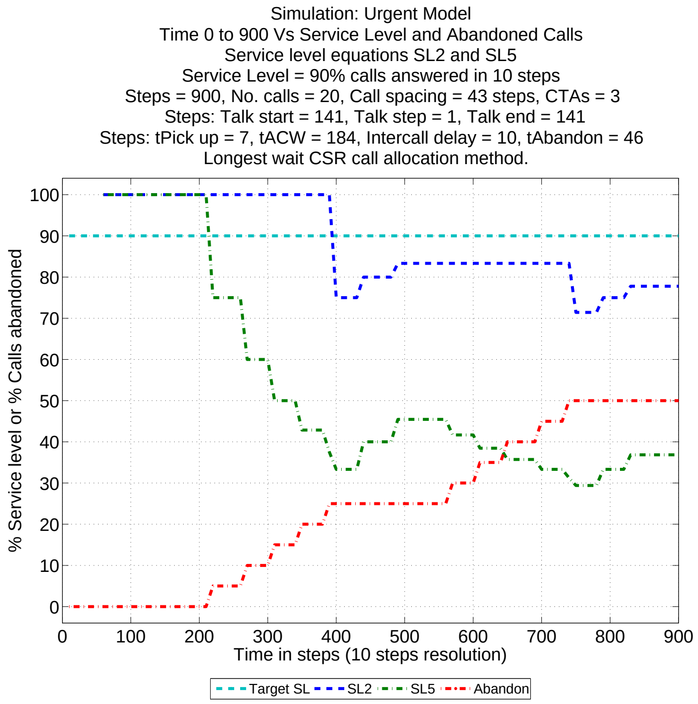


Figure 6.1: Experiment 1: Comparison of equations SL2 and SL5 model results.

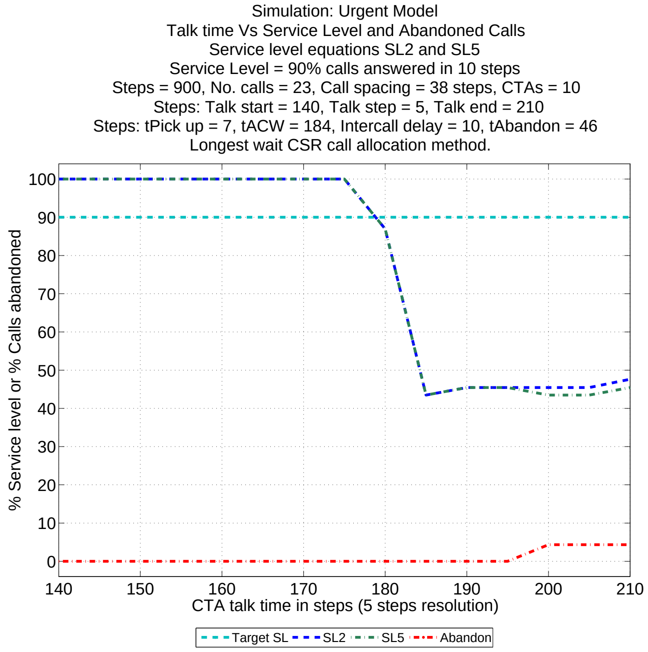
The results of this experiment highlighted the differences in call centre performance between two methods of service level calculation. Staff numbers on shift are determined from the desired service level, the forecast inbound call volume in a specified time frame and the local business rules. The method used to calculate the service level may be a local management rule or as part of the technology such as a CTI system and the choice of method will determine the staffing level. This experiment demonstrates the need for standardisation of performance measurement in the call centre industry.

6.3 Experiment 2: The effect of talk time on service level

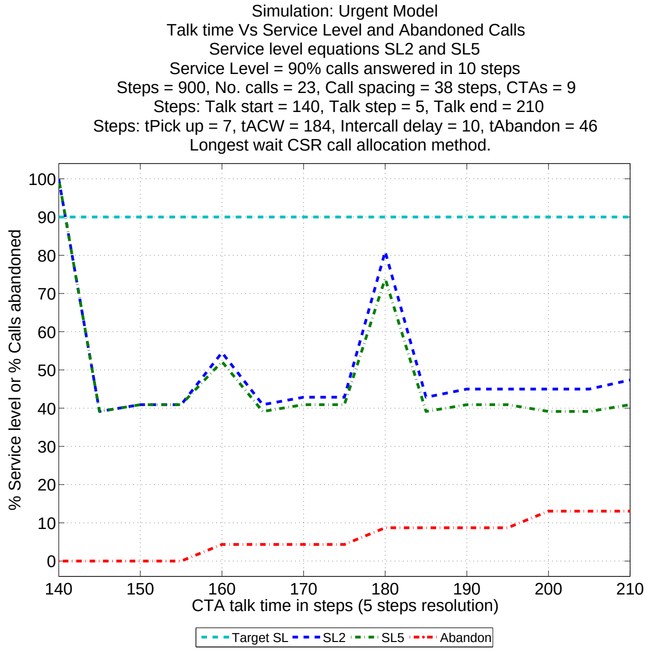
This experiment shows how changes in the CTA talk time affected the service level. The values in Table 6.2 were used as inputs to the model and the experiment was carried out in two parts. The first had 10 CTAs and the second had 9 CTAs. The talk time was varied between 140 steps and 210 steps in steps of 5 and the calls were allocated to the longest waiting CTA. At each talk time step, the model ran for 900 steps and the resulting service levels at the end of the runs were plotted.

Table 6.2: Experiment 2 input data.

Queue:	Urgent
Service level target:	90% calls answered within10 steps
Simulation period:	900 steps
Number of inbound calls:	23
Number of CTAs:	See the text
Pick up time:	7 steps
Talk time start:	140 steps
Talk time end:	210 steps
ACW time:	184 steps
Abandon time:	46 steps
Make ready/inter-call delay time:	10 steps
CTA call allocation method:	Longest waiting CTA



(a) 23 calls and 10 CTAs.



(b) 23 calls and 9 CTAs.

Figure 6.2: Experiment 2: The effect of talk time on service level.

The results in Figure 6.2 show a visual comparison between the two methods of calculating the service level using Equations 2.2 and 2.5. Figure 6.2(a) shows the result when 10 CTAs were used and Figure 6.2(b) shows the results for 9 CTAs.

The experiment demonstrates that an increase in talk time will degrade the service level. The pattern in Figure 6.2(b) is due to the model using homogeneous call and call taking agents where all time parameters are set as user-defined constants. This results in the call management process being deterministic.

The outcome of this experiment for call centre managers is to ensure that CSRs are trained and empowered to service their calls in the least time possible while providing good customer service. This is achieved at the NSWPAL by team leaders providing regular quality feedback to the CSRs together with a training, coaching and mentoring environment all of which underpin a rewards and recognition system.

6.4 Experiment 3: Response of the model to a sudden increase in calls

This experiment examined the response of the model to a sudden increase in calls or shock. The experiment was based on the events of 6 and 7 July 2007 described in Section 3.5 on p.63. The results are presented with and without abandoned calls being included using service level Equations 2.5 and 2.2 respectively so that the reader can draw a comparison on the two methods of calculation. The calls were allocated to the longest waiting CTA.

In this experiment, the model was treated as a continuous system. Consequently, the response figures show the cumulative service level throughout the simulation period and not the weighted average for successive periods identified in Koole (2007). It is important to note that the model has no memory of past time periods. So, since the aim of this experiment was to examine the models response to an input shock, the first block of 900 steps started from a ideal situation of 100% service level. The aim of the experiment was to regain the target service level of 90% calls being answered in 10 steps using additional CTA resources and the timing of their introduction. However, in attempting this, it must be borne in mind that in a real call centre CSR resources are limited with respect to staffing.

Table 6.3: Call and CSR data used for Experiment 3.

Row 1	Time[1](hh:mm):	22:30	22:45	23:00	23:15	23.30
Row 2	Friday 4 year mean calls entered[2]:	37	38	41	40	40
Row 3	NSWPAL data for Friday 6 July 2007 Triple Zero (000) queue					
Row 4	No. calls entered[3]:	37	66	75	79	54
Row 5	No. calls entered normalised to the 4 year Friday mean in Row 2:	1.0	1.7	1.8	2.0	1.4
Row 6	No. CSRs scheduled[4]:	16	16	17	17	17
Row 7	Service level[3]:	70%	0%	0%	0%	50%

[1] Start time of 15 minute block of time
[2] From Appendix A.3
[3] From Appendix B.1
[4] From Table 5.6

Table 6.3 shows the NSWPAL call and performance data and inputs for the simulation analysis period including:

- the historical means for Friday nights between 22:30 and 23:30. Each of these time markers represents the start of a 15 minute block,
- the calls entered into the Triple Zero (000) queue between 22:30 and 23:30 on Friday 6 July 2007,
- the number of calls entered as a proportion of the 4 year Friday mean. This was used to specify the size of the shock in the model,
- the number of CSRs scheduled for the Triple Zero (000) queue, and
- the resulting service level. In particular, Row 7 of Table 6.3 shows service levels of 0% for the Experiment 3 simulation period.

The experiment was run for 3 contiguous blocks of 900 steps. For consistency, it was decided to select these blocks with a similar number of four year mean calls from Row 2 of Table 6.3 so the period 23:00 to 23:30 was chosen as a basis for the experiment. The simulation time scale of 2,700 steps was divided in to three equal sections of 900 steps with the second block having the sudden increase in calls. The first and third sections were set to 40 calls each and the second section was set to 80 calls. The value of 80 resulted from an increase by a factor of 2 in accordance with Row 5 of Table 6.3 at time 23:15. The resulting distribution of calls is shown in Figure 6.3.

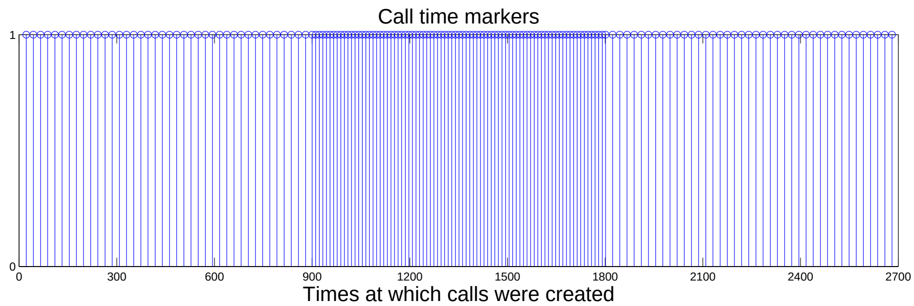


Figure 6.3: Experiment 3: Distribution of calls with unexpected increase between 900 and 1,800 steps.

Using the model with input values from Table 6.4, it was determined that 16 CTAs would be required to produce a service level of more than the target throughout a 900 step simulation period when 40 calls were entered. However, Table 6.3 shows that 17 CSRs were scheduled for the Triple Zero (000) queue for the three 15 minute periods of 11 pm to 11:45 pm and so this figure was used for this experiment.

When using 80 calls in a 900 step period in the model, it was determined that 32 CTAs were needed to produce a service level of more than the target throughout a 900 step simulation period. However, for the same period, on 6 July 2007, the

Table 6.4: Experiment 3 input values.

Queue:	Urgent
Service level target:	90% calls answered within 10 steps
Simulation period:	See text
No. calls in 900 step quiescent state:	40
No. calls in 900 step shock state:	80
Shock start time:	Step 900
Shock end time:	Step 1,800
Number of CTAs:	17 initial, then 3, 5 and 7, see text
Pick up time:	7 steps
Talk time:	141 steps
ACW time:	184 steps
Abandon time:	46 steps
Make ready/inter-call delay time:	10 steps
CTA call allocation method:	Longest waiting CTA

NSWPAL data showed that 12 CSRs were scheduled on the non-urgent queue. Since it is impractical to have an additional 16 staff on hand at this time on a Friday night for the urgent queue, it was decided to use an additional 3, 5 and 7 CTAs for the experiment and introduce these CTAs at time steps 1,200 and 1,500. In practice, these agents would transfer from the non-urgent queue to service the increased load in the urgent queue.

Figure 6.4 shows the results of running the model with the increase in calls and no additional CTAs. Prior to the increase in calls in the period up to step 900, the service level was 100%. Then the service level dropped quickly over the period 900 to 1800 steps. Equation 2.5 gave a more optimistic result than Equation 2.2. During the period 900 to 2,700 steps, the abandon level increased at a near linear rate to the unacceptable level of 40% of the entered calls and by the end of the simulation period the service level dropped below 50% for both methods of calculation.

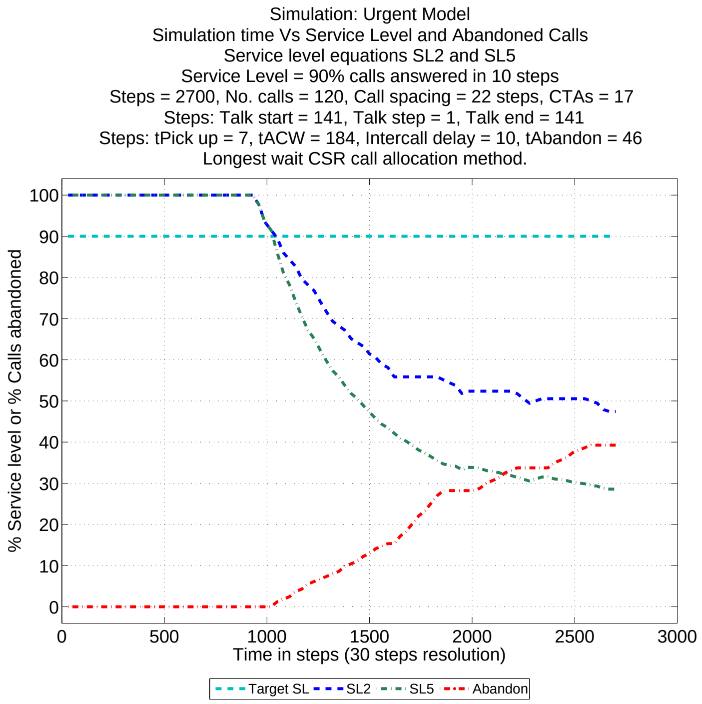


Figure 6.4: Experiment 3: The model response to a shock with no additional CTAs.

Table 6.5: Experiment 3: Service level results during the shock period with no additional CTAs.

Step:	900	1200	1500	1800
Equation SL2:	100%	78.2%	61.4%	55.8%
Difference from target:	+10%	-11.8%	-28.6%	-34.2%
Incremental change:		-11.8%	-16.8%	-5.6%
Equation SL5:	100%	67.2%	47.3%	36.4%
Difference from target:	+10%	-22.8%	-42.7%	-53.6%
Incremental change:		-22.8%	-19.9%	-10.9%

To improve this situation, additional resources were added. However, the question arose as to when was the best time to add these. In the real call centre situation this is decided by the real time managers on duty.

For this experiment the decision was made by referring to Table 6.5 which shows the service levels during the shock period at steps 900, 1,200, 1,500 and 1,800 when no additional CTAs were provided for the extra call load. Equation 2.2 was used as a basis for the decision as this method of calculation is used by the NSWPAL. Between 900 and 1,200 steps the service level dropped 11.8% from the 90% target to 78.2%, between 1,200 and 1,500 steps the drop was 16.8% to 61.4% and between 1,500 and 1,800 steps the drop was 5.6% to 55.8%.

The greatest change in service level occurred between 900 and 1,500 steps where the drop was 28.6% from the 90% target to 61.4%. In real terms this represented 10 minutes into the shock period and by that time the real time managers would have rearranged the call taking resources.

Two scenarios were examined where additional CTAs were introduced at steps 1,200 and 1,500.

6.4.1 Additional CTAs at step 1,200

A sudden drop of 11.8% at step 1,200 would alert the real time manager to consider staffing options for the falling service level. In practice the real time manager would see an increase in the number of waiting calls and start making plans to rearrange the staffing. So for this part of the experiment 3, 5 and 7 CTAs were added at step 1,200. The results are shown in Figure 6.5. The addition of 3 and 5 CTAs lessened the decline and did not improve the service level within the simulation time frame. This can be seen in Figures 6.5(a) and 6.5(b). The addition of 7 CTAs at step

1,200 again lessened the service level decline. However, after the shock period had passed beyond step 1,800 the service level began to rise. This is shown in Figure 6.5(c). These figures also show the number of CTAs throughout the process to readily identify the time step at which a change in performance is due. This facility is included in the remainder of this and in the next section.

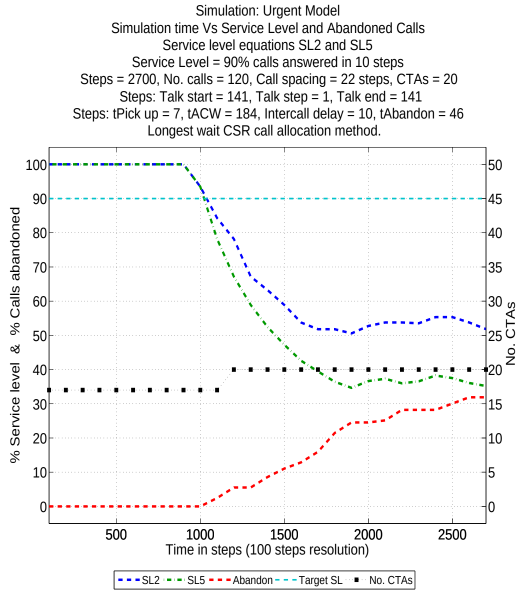
6.4.2 Additional CTAs at step 1,500

The experiment was repeated with the CTAs added at step 1,500. This could occur if was not possible to provide additional staff due to the workload of the non-urgent queue and it was necessary to wait for it to be cleared.

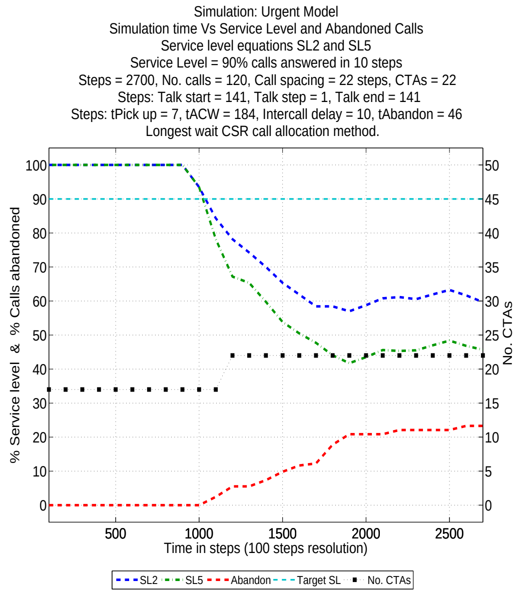
The results are shown in Figure 6.6. When 3 and 5 CTAs were added at step 1,500, there was a small increase in service level before it fell away after step 2,100. This can be seen in Figures 6.6(a) and 6.6(b). When 7 CTAs were added, the performance rose slowly and consistently towards the service level target as shown in Figure 6.6(c).

6.4.3 Extended simulation period

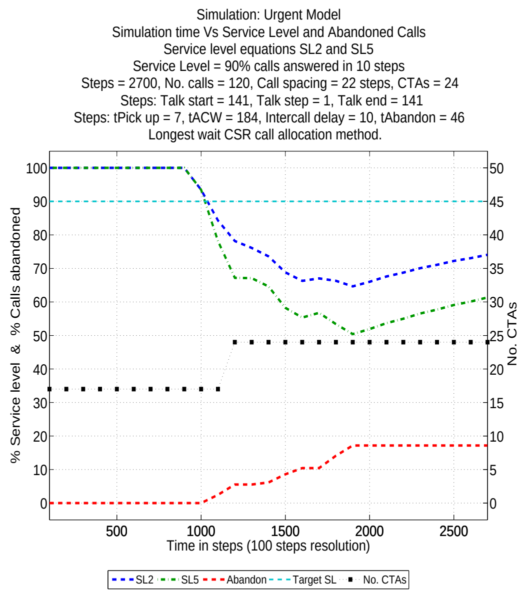
To gauge the service level recovery time constant and to see if the service level would return to the target value, the experiment was repeated over 5,400 steps with the 7 additional CTAs being added at steps 1,200 and 1,500. The call rate post shock per 900 step period was held constant at 40 calls. With reference to Figure 6.7 the service level when calculated using Equation 2.2 had not reached the 90% target by the end of the simulation period, remaining below 90% at 86.4%. The result of introducing the additional CTAs at step 1,200 can be seen in Figure 6.7(a) and showed a slight improvement compared to their introduction at step 1,500 as seen



(a) Three additional CTAs added at step 1,200.

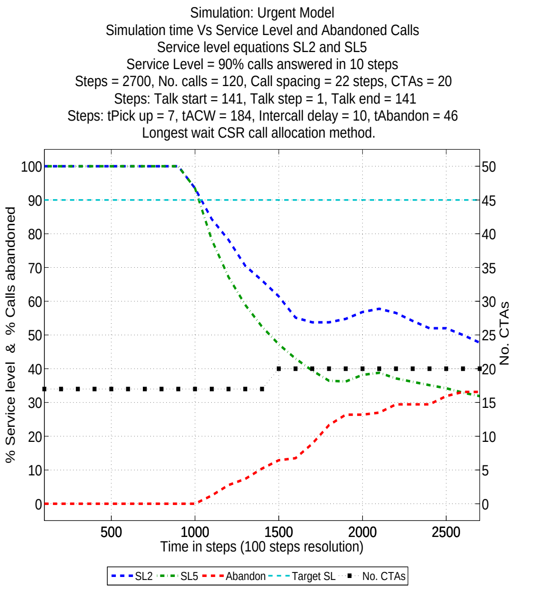


(b) Five additional CTAs added at step 1,200.

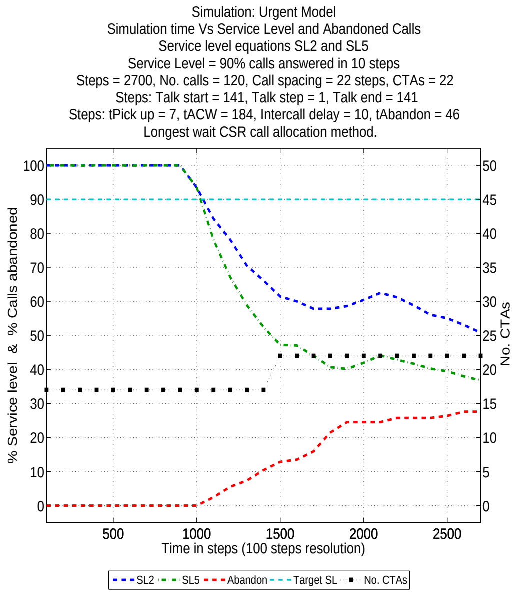


(c) Seven additional CTAs added at step 1,200.

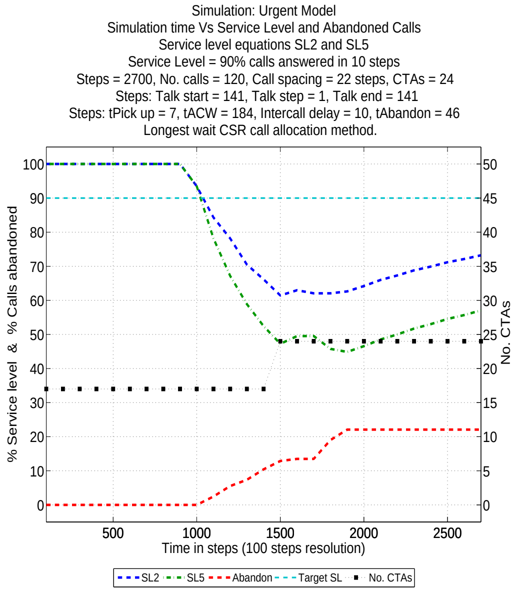
Figure 6.5: Experiment 3: Results for 3, 5 and 7 additional CTAs at time step 1,200 over 2,700 steps.



(a) Three additional CTAs added at step 1,500.



(b) Five additional CTAs added at step 1,500.



(c) Seven additional CTAs added at step 1,500.

Figure 6.6: Experiment 3: Results for 3, 5 and 7 additional CTAs at time step 1,500 over 2,700 steps.

in Figure 6.7(b). In neither case did the service level return to the target. In both cases the abandon rate levelled out to a constant value.

6.4.4 Section concluding remarks

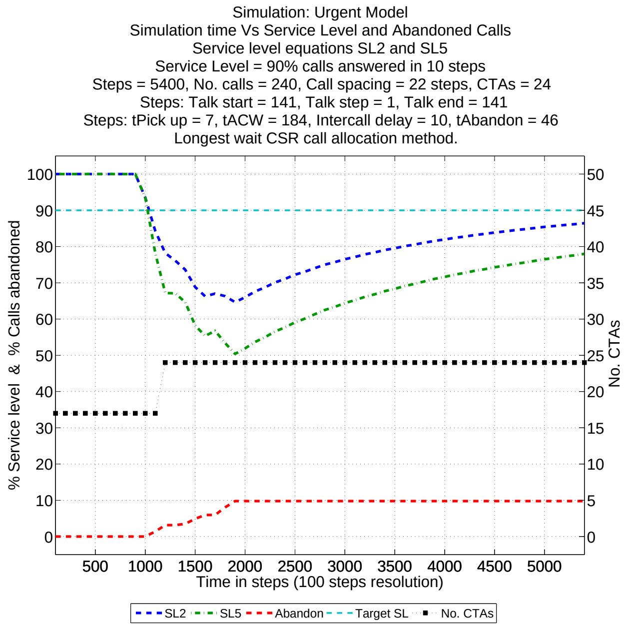
The experiment demonstrated that early intervention can lessen the impact of an unexpected increase in calls. It also identified that the recovery time constant of the model to a sudden increase in calls is slow with the performance being dependent on the number of additional resources available. It supports (Betts et al., 2000, p.185) statement that 'managers can only have a small influence on short-term performance'.

In the next experiment this was extended to examine the impact of reducing the call handle time.

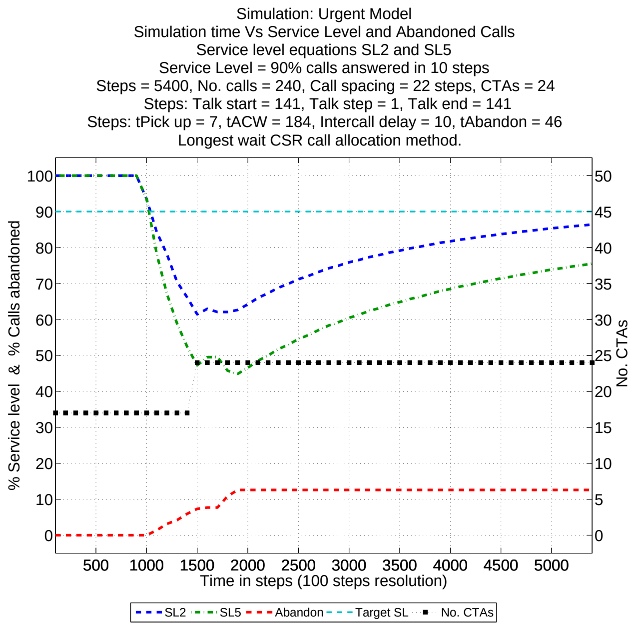
6.5 Experiment 4: Improving the service level following a sudden increase in calls by reducing call handle time

It was shown in the last experiment that modest additional resources were insufficient to bring the service level back to the target service level. In this experiment the impact of a reduction in call handle time on the service level response to a sudden increase in calls was assessed. Again the primary service level results were based on Equation 2.2. Two scenarios were examined where the call handle time was reduced by 5% and 10% and the additional CTAs were introduced at steps 1,200 and 1,500.

The model was run with the values in Table 6.6 and calls were allocated to the longest waiting CTA. Both the talk time and the ACW time were reduced first by 5% and then by 10%. These are shown in Table 6.6.



(a) Simulation period 5,400 steps with 7 additional CTAs added at step 1,200.



(b) Simulation period 5,400 steps with 7 additional CTAs added at step 1,500.

Figure 6.7: Experiment 3: Service level recovery test results for 7 additional CTAs at time steps 1,200 and 1,500 over a 5,400 step period.

Table 6.6: Experiment 4 input values.

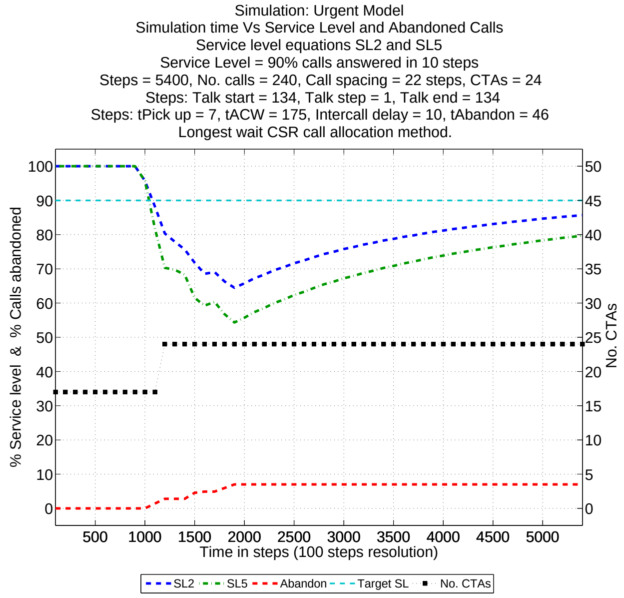
Queue:	Urgent	
Service level target:	90% calls answered within 10 steps	
Simulation period:	5,400 steps	
No. calls in 900 step quiescent state:	40	
No. calls in 900 step shock state:	80	
Number of CTAs up to 1,500 steps:	17	
Number of CTAs after 1,500 steps:	24	
Pick up time:	7 steps	
Handle time reduction	5%	10%
Talk time:	134 steps	127 steps
ACW time:	175 steps	166 steps
Abandon time:	46 steps	
Make ready/inter-call delay time:	10 steps	
CTA call allocation method:	See text	

The 5% reduction in handle time did not return the service level to the target as seen in Figure 6.8. However the 10% reduction, Figure 6.9, did return the service level to target when the additional CTAs were introduced at steps 1,200 and 1,500 with the former occurring at step 3,300 and the latter at step 4,600. These results are summarised in Table 6.7.

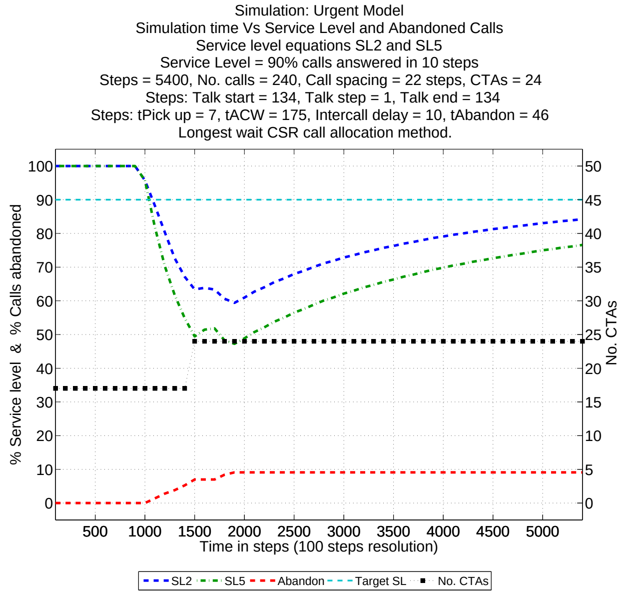
Table 6.7: Experiment 4: Service level results returned to target based on Equation 2.2 following the shock period with a reduction in call handle time.

	Handle time reduction	
	5%	10%
Additional CTAs at step 1,200		
Step at which service level returned to target	No result	3,300
Additional CTAs at step 1,500		
Step at which service level returned to target	No result	4,600

It should also be noted that in both cases the service level calculated with abandoned calls using Equation 2.5 is far from the target.

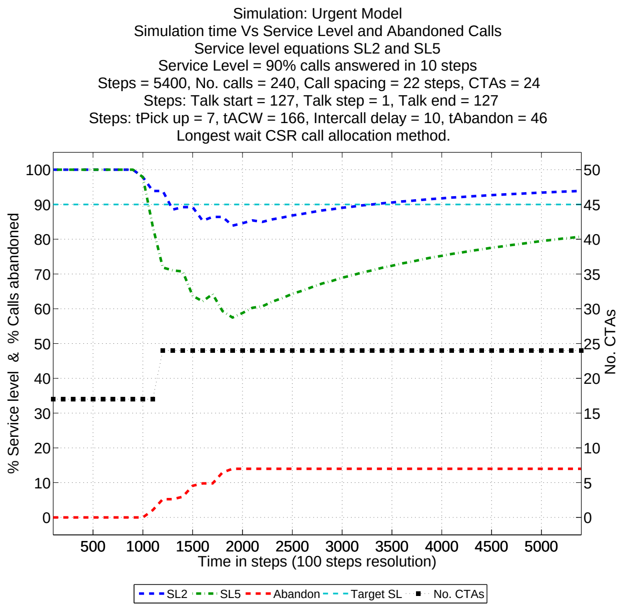


(a) Simulation period 5,400 steps with 7 additional CTAs added at step 1,200 with 5% reduction in handle time.

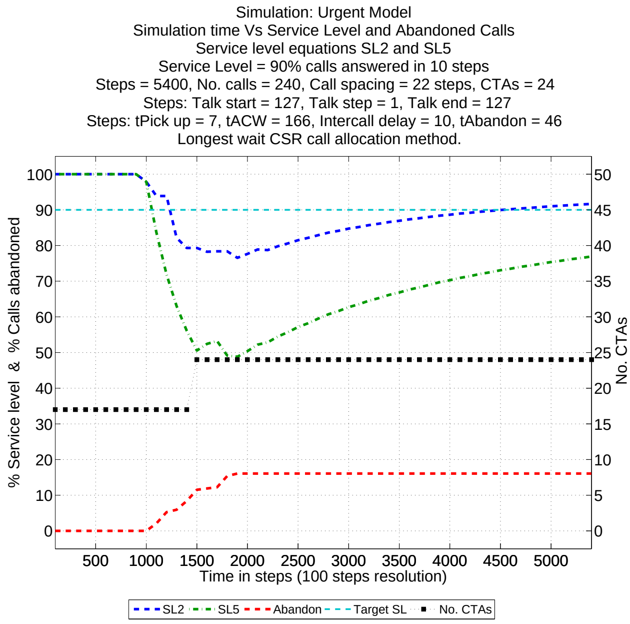


(b) Simulation period 5,400 steps with 7 additional CTAs added at step 1,500 with 5% reduction in handle time.

Figure 6.8: Experiment 4: Results for 7 additional CTAs at time steps 1,200 and 1,500 over a 5,400 step period with 5% reduction in handle time.



(a) Simulation period 5,400 steps with 7 additional CTAs added at step 1,200 with 10% reduction in handle time.



(b) Simulation period 5,400 steps with 7 additional CTAs added at step 1,500 with 10% reduction in handle time.

Figure 6.9: Experiment 4: Results for 7 additional CTAs at time steps 1,200 and 1,500 over a 5,400 step period with 10% reduction in handle time.

6.6 *Experiment 5: Different methods of allocating calls to CTAs*

The model provides for four methods of allocating calls to a CTA. These were discussed in Chapter 4 and are:

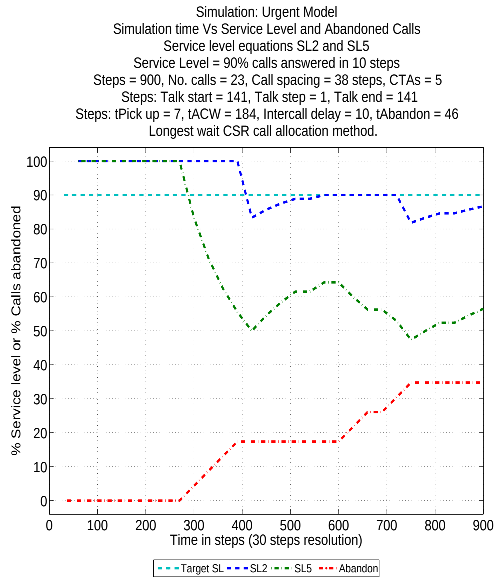
- longest waiting CTA. This is the method used by the NSWPAL and is seen as a fair way of allocating calls,
- shortest waiting CTA,
- hierarchical, based on the CTA's unique identifier from, say, top to bottom, and
- random.

This experiment implemented each of these against the data in Table 6.8. The model was run for 900 steps and all variables except the CTA call allocation method were held constant.

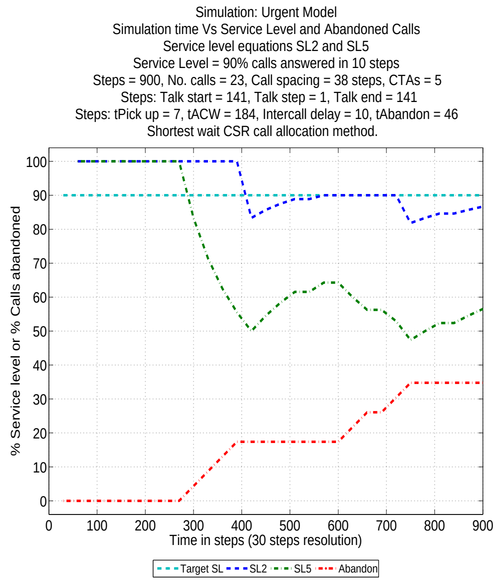
Table 6.8: Experiment 5 input data.

Queue:	Urgent
Service level target:	90% calls answered within10 steps
Simulation period:	900 steps
Number of inbound calls:	23
Number of CTAs:	5
Pick up time:	7 steps
Talk time:	141 steps
ACW time:	184 steps
Abandon time:	46 steps
Make ready/inter-call delay time:	10 steps
CTA call allocation method:	See text

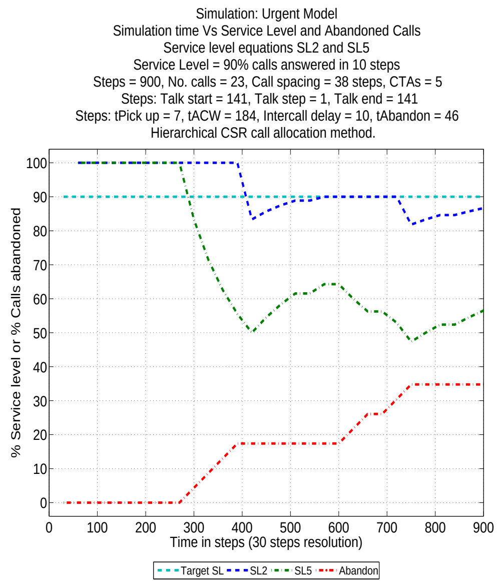
The results of the experiment are summarised in Figure 6.10 where it was found that the model was insensitive to changes in the call allocation method. This can be seen in Figures 6.10(a), 6.10(b) and 6.10(c) for the longest waiting CTA, the shortest waiting CTA and the hierarchical allocation methods respectively. Figure 6.10(d)



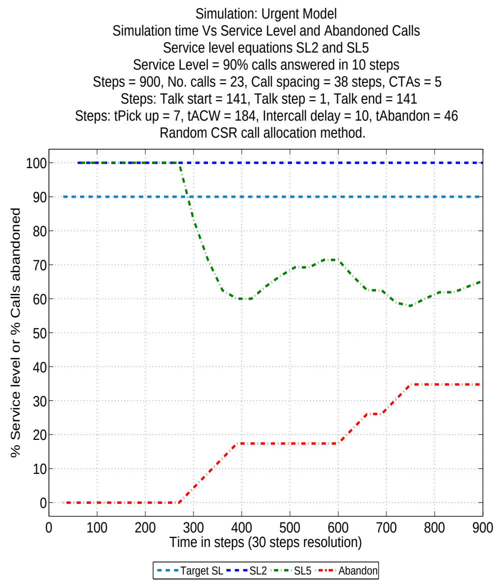
(a) Longest waiting CTA.



(b) Shortest waiting CTA.



(c) Hierarchical.



(d) Random.

Figure 6.10: Experiment 5: Results for different call allocation methods.

Table 6.9: Urgent model call results for the following parameters ...
Service Level target = 90 percent of calls answered in 10 steps
CTA call allocation method: Random
Simulation time = 900 steps, No. calls = 23, Number of call takers = 5
Pickup time = 7 steps, Talk time start = 141 steps, Talk time end = 141 steps,
ACW time = 184 steps, Inter-call delay time = 10 steps, Abandon time = 46 steps.

Call ID	Time call entered	Time call allocated	Time pick up ended	Time call answered	Time to answer call	Time talk ended	Time call ended	State	CTA ID	Time call abandoned
101	38	38	45	46	8	186	370	Finished	713	0
102	76	76	83	84	8	224	408	Finished	714	0
103	114	114	121	122	8	262	446	Finished	712	0
104	152	152	159	160	8	300	484	Finished	715	0
105	190	190	197	198	8	338	522	Finished	711	0
106	228	0	0	0	-1	0	0	Abandoned	0	274
107	266	0	0	0	-1	0	0	Abandoned	0	312
108	304	0	0	0	-1	0	0	Abandoned	0	350
109	342	381	0	0	-1	0	0	Abandoned	713	388
110	380	381	388	389	9	529	713	Finished	713	0
111	418	419	426	427	9	567	751	Finished	714	0
112	456	457	464	465	9	605	789	Finished	712	0
113	494	495	502	503	9	643	827	Finished	715	0
114	532	533	540	541	9	681	865	Finished	711	0
115	570	0	0	0	-1	0	0	Abandoned	0	616
116	608	0	0	0	-1	0	0	Abandoned	0	654
117	646	0	0	0	-1	0	0	Abandoned	0	692
118	684	724	0	0	-1	0	0	Abandoned	713	730
119	722	724	731	732	10	872	0	End talk	713	0
120	760	762	769	770	10	0	0	Talk	714	0
121	798	800	807	808	10	0	0	Talk	712	0
122	836	838	845	846	10	0	0	Talk	715	0
123	874	876	883	884	10	0	0	Talk	711	0

Table 6.10: Urgent model call results for the following parameters ...
Service Level target = 90 percent of calls answered in 10 steps
CTA call allocation method: Random
Simulation time = 900 steps, No. calls = 23, Number of call takers = 5
Pickup time = 7 steps, Talk time start = 141 steps, Talk time end = 141 steps,
ACW time = 184 steps, Inter-call delay time = 10 steps, Abandon time = 46 steps.

Call ID	Time call entered	Time call allocated	Time pick up ended	Time call answered	Time to answer call	Time talk ended	Time call ended	State	CTA ID	Time call abandoned
101	38	38	45	46	8	186	370	Finished	714	0
102	76	76	83	84	8	224	408	Finished	715	0
103	114	114	121	122	8	262	446	Finished	712	0
104	152	152	159	160	8	300	484	Finished	711	0
105	190	190	197	198	8	338	522	Finished	713	0
106	228	0	0	0	-1	0	0	Abandoned	0	274
107	266	0	0	0	-1	0	0	Abandoned	0	312
108	304	0	0	0	-1	0	0	Abandoned	0	350
109	342	381	0	0	-1	0	0	Abandoned	714	388
110	380	381	388	389	9	529	713	Finished	714	0
111	418	419	426	427	9	567	751	Finished	715	0
112	456	457	464	465	9	605	789	Finished	712	0
113	494	495	502	503	9	643	827	Finished	711	0
114	532	533	540	541	9	681	865	Finished	713	0
115	570	0	0	0	-1	0	0	Abandoned	0	616
116	608	0	0	0	-1	0	0	Abandoned	0	654
117	646	0	0	0	-1	0	0	Abandoned	0	692
118	684	724	0	0	-1	0	0	Abandoned	714	730
119	722	724	731	732	10	872	0	End talk	714	0
120	760	762	769	770	10	0	0	Talk	715	0
121	798	800	807	808	10	0	0	Talk	712	0
122	836	838	845	846	10	0	0	Talk	711	0
123	874	876	883	884	10	0	0	Talk	713	0

shows that it was only the random allocation method that produced an improved result.

The reason for this can be seen by looking at the results throughout the simulation period. This is best illustrated by comparing the results of two simulation runs using the random allocation method and can be seen in Tables 6.9 and 6.10. Referring to the 10th column in these tables, it can be seen that although the calls were allocated to different CTAs throughout the time period, the timing patterns did not change.

The reason for the non-stochastic nature of the results is because the model uses homogeneous call and call taking agents. This resulted in the call management process being highly predictable since all time parameters are set as user-defined constants.

As the model develops in the future, it is proposed to introduce different subclasses of calls and CTAs with each subclass having a different set of parameters.

6.7 *Experiment 6: Service level calculation anomaly at the start of the day*

Operational systems such as the NSWPAL generate statistics in real time throughout the day and these are used by the shift managers and team leaders to monitor and manage the overall call centre performance.

The real-time monitoring of call centre performance is programmed to present the statistics throughout the day with calculations starting from an agreed time of, say, midnight. When calculating the service level, equations such as Equations 2.2 and

2.5 are used. However, at the start of the day an anomaly occurs in the service level calculation until the first call is answered when these equations are used. This experiment demonstrates this anomaly.

The model was run for 20 steps with 1 call being entered at step 10. The input data to the model is shown in Table 6.11. The first call was entered at step 10 and immediately allocated to a CTA. The CTA then took 7 steps to pick the call up and this process ended at step 17. The call was answered by the CTA at step 18.

Table 6.11: Experiment 6 input data.

Queue:	Urgent
Service level target:	90% calls answered within10 steps
Simulation period:	20 steps
Number of inbound calls:	1
Number of CTAs:	3
Pick up time:	7 steps
Talk time:	141 steps
ACW time:	184 steps
Abandon time:	46 steps
CTA call allocation method:	Longest waiting

The results from the model at time steps 17 and 18 are shown in Tables 6.12 and 6.13. Table 6.12 shows the results after 17 time steps where a total of zero calls were answered and zero calls were answered within the AWT. Substituting these values into Equations 2.2 and 2.5 gives an indeterminate result of 0/0. On the other hand, applying the Erlang C Equations 2.8 to 2.13 gives a value of 100%. In the case of NSWPAL, the CTI display system shows 0% for the service level until a call is received.

Table 6.13 shows the results after 18 time steps. Here, one call was answered and one call was answered within the AWT giving a service level of 100% when using Equations 2.2, 2.5 and the Erlang C model.

Table 6.12: Experiment 6: Results at time 17 steps.

Total calls answered:	0
Total calls answered within AWT:	0
Total calls answered after AWT:	0
Service levels	
Equation SL2:	Indeterminate
Equation SL5:	Indeterminate
Erlang C model:	100.0%

Table 6.13: Experiment 6: Results at time 18 steps.

Total calls answered:	1
Total calls answered within AWT:	1
Total calls answered after AWT:	0
Service levels	
Equation SL2:	100.0%
Equation SL5:	100.0%
Erlang C model:	100.0%

6.8 Experiment 7: Using historical data to assess performance

Here the historical data option was selected and calls between 11 pm and 11:15 pm on a Friday night for the urgent queue were selected. The number of calls generated using the summary data as a base was 32 which can be seen in Appendix A.3 on p.168. The generated call sequence is shown in Figure 6.11.

The number of CTAs was chosen to force calls to abandon and demonstrate the utility of the model. The model's response is seen in Figure 6.12. Such a facility would allow call centre managers to undertake "what if?" testing with different agent and call parameters before committing staff schedules.

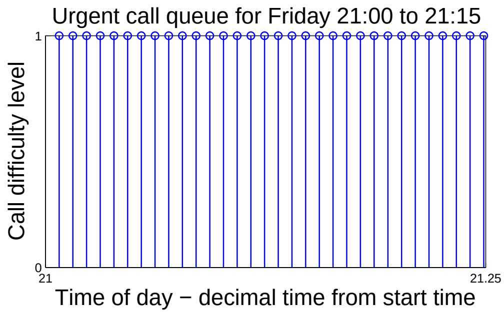


Figure 6.11: Experiment 7: Friday night historical calls generated.

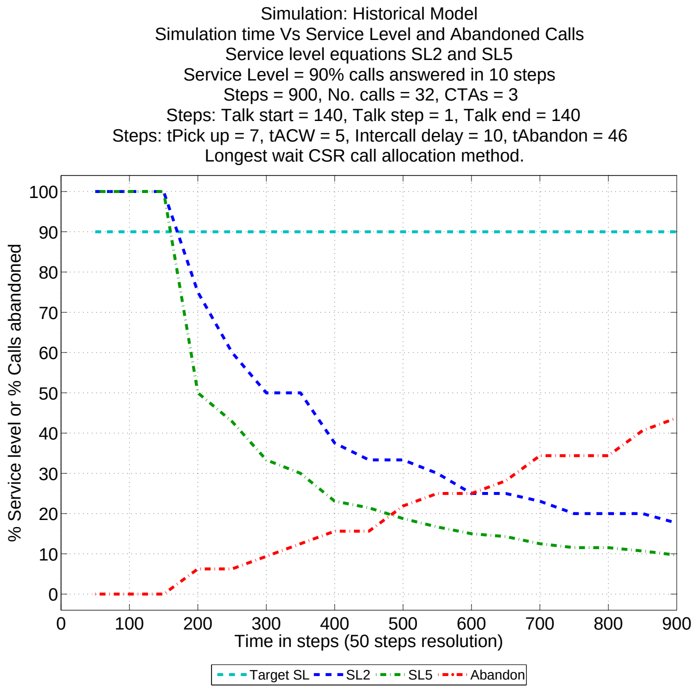


Figure 6.12: Experiment 7: Friday night response using historical data.

6.9 Experiment 8: Comparing the thesis and Erlang C models

In Section 2.3.3 the use of the Erlang C model was discussed where it was revealed that its use was for the estimation of stationary system performance over short intervals (Gans et al., 2003, p.14). In Section 2.3.4 it was explained that where the offered load exceeded the number of CSRs, the service level as calculated by the Erlang C model's Equation 2.13 goes negative and so has no meaning. In such cases, the service level is set to zero in the thesis model.

In this experiment the use of Equation 2.2 is compared with the Erlang C model in assessing service level. The model was set to run for 900 steps with no calls abandoning. The input data for the experiment is shown in Table 6.14.

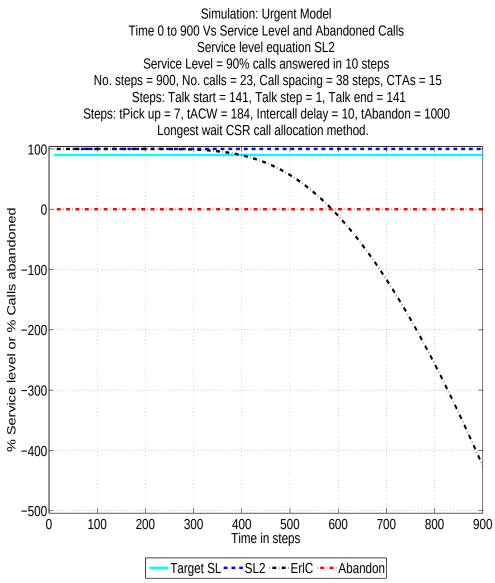
Table 6.14: Experiment 8 input data.

Queue:	Urgent
Service level target:	90% calls answered within10 steps
Simulation period:	900 steps
Number of inbound calls:	23
Number of CTAs:	15, 10 and 5
Pick up time:	7 steps
Talk time:	141 steps
ACW time:	184 steps
Abandon time:	1000 steps
Make ready/inter-call delay time:	10 steps
CTA call allocation method:	See text

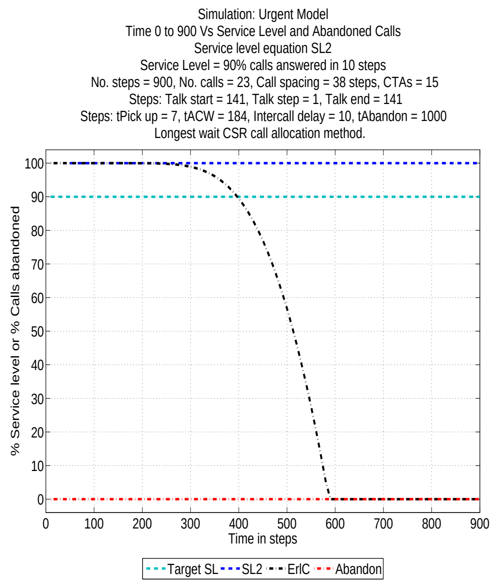
The results of the experiment are shown graphically in Figure 6.13. Figure 6.13(a) shows the results where 15 CTAs were used and the service level calculated using the Erlang C model is unrestricted. At time step 587 the service level fell to zero and although a negative service level beyond this point has no meaning the results are shown for completeness. Figure 6.13(b) shows the same results with the service level calculated using the Erlang C model restricted to no less than zero as described above. In both cases, the service level remained at 100% when using Equation 2.2.

In Figure 6.13(c) 10 CTAs were used and the service level fell to zero at time step 400 with the Erlang C model and stayed at 100% with Equation 2.2.

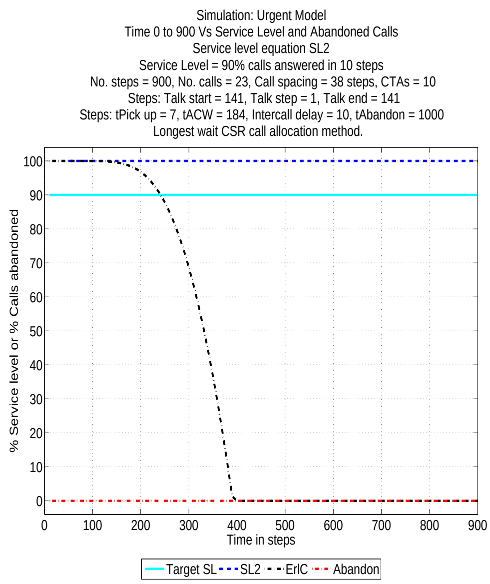
In Figure 6.13(d) the number of CTAs was reduced to 5 to simulate understaffing. The service level fell to zero at time step 200 with the Erlang C model and stayed



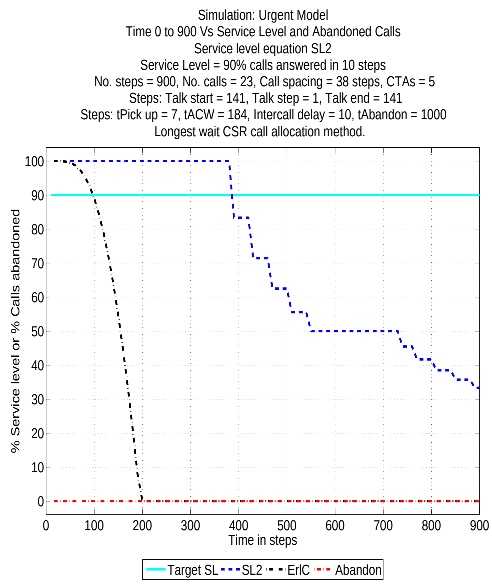
(a) 15 CTAs.



(b) 15 CTAs.



(c) Ten CTAs.



(d) Five CTAs.

Figure 6.13: Experiment 8: Comparing the thesis and Erlang C models.

at 100% with Equation 2.2 until time step 380. From this point, the service level fell and was 33.3% at the end of the simulation period.

This experiment demonstrated that in contrast to the Erlang C model the thesis model is not stationary and the contribution of the individual call takers is taken into account over the simulation period.

6.10 Concluding remarks

The method of calculating a call centre's service level is at the discretion of the call centre manager. Such methods include and exclude abandoned calls. In this chapter Equations 2.2 and 2.5 were used as being representatives of these methods and to show the differences in results. The first equation excludes abandoned calls and the second includes abandoned calls.

The experiments in the chapter demonstrated that the model was able to provide results that emulated the performance of an emergency call centre.

The effect of using different methods to calculate the service level with a common set of data was demonstrated. Irrespective of the method used, the change in service level when the CTA talk time increased was also demonstrated.

The service level calculation methods identified an anomaly in service level at the start of a call centre's daily performance measurement.

When the model was subjected to a sudden increase in calls, it was found to have a slow recovery time constant. Over the simulation time it was not possible to return the service level to the target level with an increase in staff of 41%. This was an expected outcome due to call centres having limited call taking resources and the fact that the nature of the inbound calls necessitate large process times. However it was found that, with this increased number of CTAs, a 10% decrease in handle time brought the service level back onto the target.

Four different methods of allocating calls to CTAs were examined and it was demonstrated that the model with homogeneous agents was insensitive to the different methods. This pointed to how the model could be extended in the future.

Finally, the performance of the model when determining service level was compared with the Erlang C model where it was found that the thesis model was not stationary and that the contribution of the individual call takers was taken into account over the simulation period.

In the next chapter concluding remarks are made and future work to extend this research is discussed.

Chapter 7

CONCLUSIONS AND FUTURE WORK

This thesis has described and demonstrated that a simple agent-based computer model is able to simulate the relationship between call centre call takers and their call queues in an emergency call centre.

Data for the research were based on the NSWPAL urgent and non-urgent daily queue management reports. These reports are used by the NSWPAL managers to assess the previous day's performance and are based on agreed metrics within the NSW Police Force. The reports were analysed over a four year period and tabular and graphical summaries were presented. It was found from this analysis that the daily call profiles for the NSWPAL non-urgent queue were similar to inbound call profiles found in the literature. However, this was not so for the urgent queue where no detailed analysis of the emergency inbound calls to police facility was found making this a significant contribution of this thesis.

In Chapter 6 a collection of experiments demonstrated the capabilities of the model. Two of the experiments showed anomalies associated with the common methods of calculating service level. One of the topics debated in the calculation of service level was whether or not abandoned call should be included. The differences between the methods of calculation were demonstrated in this chapter and in other chapters of this thesis. Be as it may, the point was made in this thesis that the method of calculation is at the discretion of the call centre managers. This demonstrates the need for standardisation of performance measurement in the call centre industry.

The model was subjected to a sudden increase in calls and the response of the model recorded. This resulted in the service level dropping quickly. To manage the situation, additional call taking resources were added. The number and timing of these was determined through running the model with different input values and analysing the results. In all cases, it was found that the model had a long recovery time constant and within the bounds of the parameters for this experiment it was not possible to return the service level to the target value. In a second part to this experiment it was shown that by decreasing the call handle time by 10% across the simulation period, it was possible to return the service level to the target value.

An extension of this experiment was undertaken where the impact of the call handle time was assessed. It was found that a modest decrease of 10% was sufficient to bring the service level back to the target level. However, this still occurred over a long time frame and was dependent on the service level calculation method.

In the next experiment, four different methods of allocating calls to the call taking agents were assessed. It was found that the model was insensitive to changes in the call allocation method. However when the calls were allocated randomly the results improved with the level of improvement dependent on the service level calculation method.

After this it was demonstrated that historical summary statistics could be used as a basis for the prediction of call centre performance.

Finally, it was shown that when comparing the performance of the thesis and Erlang C models, the thesis model demonstrated that the contribution of the individual call takers were taken into account over the simulation period.

These experiments demonstrated that the model was capable of providing results that emulated the performance of an emergency call centre.

7.1 Future work

Throughout the course of this research additional work came to light that could extend the operation, performance and utility of the model described in this thesis.

The results in this thesis have a non-stochastic nature. This is because the model uses homogeneous call and call taking agents. This resulted in the call handling process being deterministic since all time parameters were set as user-defined constants. As the model develops in the future, it is proposed to introduce different subclasses of calls and CTAs with each subclass having a different set of parameters.

In summary, the following are potential topics for future research and work:

- introduce stochastic variability call time spacing for inbound calls,
- introduce call categories where each category has a specific level of the difficulty of the call. This is especially so for non-urgent calls. In the case of NSWPAL there are a variety of non-urgent call categories and each has its own set of parameters. This requires the identification, analysis and summarising of the call categories to determine these parameters,
- introduce a minimum of three call taking agent subclasses to cover a range of low, average and high performers. These parameters could be calibrated against de-identified CSR data,
- introduce stochastically variable call taking agent parameters,
- introduce a set of middle managers in the form of team leaders to make decisions based on call centre performance parameters such as, the number of waiting calls, the average speed of answer and the service level,

- extend the model to concurrent multi-queue operation. While the current model is capable of simulating both urgent and non-urgent queues, these are currently handled on an individual basis,
- provide separate functions within the model to vary the number of agents, the call abandon time, the call pickup time, the after call work time, and the make ready time between user-defined start, end, and step values. While provision has been made in the graphical interface, the routines have not been written,
- change the model such that it is able to start a simulation from a previous state. In its current form, the model starts its simulation from the ideal situation where the service level is 100%, and
- develop a call centre performance metric that could be used as a standard throughout the call centre industry.

7.2 A final word

The model described in this thesis forms the basis for developing a tool that will provide call centre mangers with a means of testing different operational scenarios and testing call centre performance with different model parameters. While the focus of this thesis has been on the emergency call centre, the model is capable of being used more generally.

It was demonstrated that agent-based modelling consisting of a few agent classes and simple timing loops can be used instead of a complex mathematical model. Such a model necessarily includes the contribution of the individual agents in achieving an holistic outcome.

Such an instrument, can be used by the call centre industry to examine the way that CSR and call parameters influence call centre performance and to examine the impact of different measurement techniques on emergent performance.

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Appendix A

HISTORICAL DATA SUMMARIES

A.1 *Historical non-urgent queue summary means*

Table A.1: Non-urgent queue means of calls received by quarter hour for the period January 2005 to December 2008

Decimal time	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
0.00	8.76	3.82	3.36	3.48	3.65	4.43	7.61
0.25	8.32	3.04	2.91	3.08	3.32	3.56	6.63
0.50	7.53	2.90	2.53	2.78	2.87	3.33	6.32
0.75	7.06	2.48	2.16	2.30	2.59	3.15	6.00
1.00	6.89	2.11	1.92	1.90	2.19	2.69	5.66
1.25	6.12	2.15	1.90	1.84	2.14	2.40	5.15
1.50	5.55	1.77	1.73	1.50	1.88	2.15	4.78
1.75	5.26	1.55	1.41	1.43	1.74	1.88	4.36
2.00	4.62	1.55	1.38	1.36	1.32	1.90	4.05
2.25	4.76	1.41	1.24	1.27	1.53	1.66	3.88
2.50	4.30	1.40	1.07	1.09	1.46	1.55	3.42
2.75	4.11	1.36	1.02	1.15	1.38	1.43	3.58
3.00	3.56	1.28	0.99	1.01	1.32	1.33	3.07
3.25	3.37	1.11	0.94	0.92	1.07	1.33	2.88
3.50	3.44	1.09	0.88	0.99	1.17	1.30	2.58
3.75	3.01	1.00	0.90	1.05	1.04	1.27	2.73
4.00	2.77	1.09	0.85	0.80	1.21	1.20	2.38
4.25	2.73	0.98	0.89	0.89	1.08	1.15	2.43
4.50	2.27	1.12	0.95	1.00	1.16	1.22	2.22
4.75	2.11	1.16	0.96	0.95	1.24	1.23	2.08
5.00	2.01	1.60	1.31	1.43	1.23	1.40	2.11
5.25	1.97	1.88	1.47	1.57	1.78	1.74	2.09
5.50	1.83	2.11	2.04	1.91	2.23	2.03	2.24
5.75	2.01	3.22	2.72	2.61	2.78	2.74	2.52
6.00	2.40	4.19	3.80	3.76	3.59	3.83	2.99
6.25	2.68	4.68	4.46	4.36	4.39	4.56	3.50
6.50	3.53	6.09	6.27	5.70	5.81	6.17	4.38
6.75	4.03	7.90	7.47	6.97	7.54	7.14	5.34
7.00	4.87	11.85	10.67	9.98	10.25	9.85	6.72
7.25	6.11	13.64	11.80	11.55	11.72	11.65	8.28
7.50	7.18	16.85	13.88	13.63	13.30	12.96	9.89
7.75	8.18	19.95	15.55	15.36	15.24	14.70	11.40
8.00	10.47	25.03	19.22	18.65	18.94	18.60	14.15

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Table A.1 – continued from previous page

Decimal time	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
8.25	11.19	27.25	21.76	20.51	21.01	19.98	15.49
8.50	12.73	32.70	25.16	23.44	24.54	23.71	17.00
8.75	13.79	37.87	28.71	26.67	27.34	26.80	18.11
9.00	15.77	43.31	33.81	31.11	31.56	30.85	21.04
9.25	17.53	46.92	35.98	33.57	33.88	32.50	21.75
9.50	17.96	48.29	36.71	35.00	34.01	33.36	22.94
9.75	18.22	45.95	35.96	33.68	32.35	32.13	22.50
10.00	20.37	45.56	35.66	33.75	33.02	32.14	25.08
10.25	21.01	44.50	34.94	32.39	31.76	32.13	24.48
10.50	21.22	42.79	34.16	31.48	31.49	31.14	23.84
10.75	20.84	40.45	33.19	30.76	30.78	30.14	23.19
11.00	22.02	39.48	32.63	30.96	30.07	30.65	24.09
11.25	21.11	40.35	31.90	30.62	29.62	30.20	22.94
11.50	20.49	38.17	31.94	30.20	29.75	29.15	23.05
11.75	20.44	36.80	30.75	28.92	27.93	27.96	21.87
12.00	20.21	36.49	30.74	29.24	27.70	27.23	22.97
12.25	20.40	35.24	29.17	28.30	27.70	27.33	21.46
12.50	19.28	34.21	28.59	27.36	26.64	26.61	20.80
12.75	18.46	33.20	28.07	27.15	25.91	26.47	20.72
13.00	19.12	32.99	28.69	27.79	26.91	26.73	20.30
13.25	17.86	32.54	28.39	26.95	26.51	26.61	19.79
13.50	17.54	32.82	28.28	27.35	26.57	26.40	19.72
13.75	16.53	32.06	28.08	26.37	26.12	25.21	17.39
14.00	17.78	33.03	29.25	28.76	27.97	27.65	18.69
14.25	16.94	32.84	29.48	28.20	28.15	27.91	18.22
14.50	16.67	33.56	29.23	28.02	27.53	27.20	18.01
14.75	15.73	31.37	28.34	27.32	26.29	26.11	16.99
15.00	16.83	33.71	30.28	28.56	28.34	29.33	18.66
15.25	15.97	32.85	30.07	29.04	28.52	28.58	17.84
15.50	16.35	33.64	30.39	29.46	29.05	29.60	17.76
15.75	16.45	33.30	30.13	29.21	28.95	28.50	17.05
16.00	17.30	35.06	32.37	31.69	31.22	29.85	17.60
16.25	17.05	33.63	31.29	30.56	29.28	28.70	17.36
16.50	17.19	32.83	30.64	29.16	28.64	27.88	17.52
16.75	16.56	31.07	28.88	28.22	27.13	25.98	16.51
17.00	17.04	29.20	27.42	26.66	26.48	25.11	17.20
17.25	17.17	26.90	25.65	24.84	24.16	23.15	17.20
17.50	16.10	25.26	24.00	23.48	22.10	21.71	17.14
17.75	15.44	23.12	21.41	21.19	20.58	20.25	15.23
18.00	14.82	22.90	20.76	20.10	20.00	20.15	15.82
18.25	14.79	21.96	20.60	20.09	19.29	19.21	15.12
18.50	14.08	20.50	19.58	19.09	18.38	18.86	14.35
18.75	13.60	19.11	18.29	17.35	17.65	17.46	13.12
19.00	13.43	18.55	17.68	16.69	16.75	16.13	12.86
19.25	12.92	16.72	16.24	15.94	15.65	15.32	11.96
19.50	12.00	16.22	15.58	15.04	15.25	14.70	11.17
19.75	11.34	14.87	14.15	14.10	14.21	13.61	10.54
20.00	11.44	14.67	14.02	14.20	14.02	12.46	10.17
20.25	11.22	13.56	13.13	12.70	13.35	12.29	10.26
20.50	11.04	12.71	12.21	12.45	12.92	11.50	9.58
20.75	10.49	11.16	11.40	10.94	12.14	10.93	9.59
21.00	9.57	11.15	10.77	10.91	12.12	10.60	9.11
21.25	9.41	10.24	10.51	9.92	11.73	10.12	9.14

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Table A.1 – continued from previous page

Decimal time	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
21.50	8.89	9.83	9.92	9.61	11.73	10.03	9.22
21.75	8.19	8.61	8.56	8.92	9.73	9.07	8.83
22.00	7.90	8.00	8.04	8.31	9.63	9.69	9.27
22.25	7.49	7.52	7.71	8.26	9.33	10.24	9.92
22.50	6.63	7.01	7.09	7.26	7.89	9.34	9.20
22.75	6.01	5.80	6.68	6.29	6.84	8.88	8.46
23.00	5.78	5.21	5.77	5.89	6.59	8.90	8.89
23.25	5.04	4.59	4.92	5.28	5.97	8.18	8.46
23.50	4.49	4.05	4.40	4.54	5.06	7.72	8.46
23.75	3.50	3.37	3.44	3.78	4.49	6.88	7.22

A.2 Historical non-urgent queue summary SDs

Table A.2: Non-urgent queue Standard Deviations of calls received by quarter hour for the period January 2005 to December 2008

Decimal time	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
0.00	3.16	2.35	2.42	2.06	2.36	2.48	2.74
0.25	3.40	2.04	2.01	1.92	1.88	2.12	2.85
0.50	2.70	2.06	2.04	1.85	1.85	1.91	2.78
0.75	2.93	1.94	2.04	1.77	1.83	2.01	2.61
1.00	3.19	1.96	1.66	1.65	1.56	1.95	2.42
1.25	2.92	1.77	1.67	1.33	1.57	1.63	2.47
1.50	2.96	2.00	1.70	1.28	1.50	1.59	2.64
1.75	2.52	1.71	1.72	1.27	1.38	1.46	2.56
2.00	2.50	1.76	1.57	1.28	1.20	1.44	2.11
2.25	2.60	1.50	1.42	1.16	1.26	1.38	2.10
2.50	2.27	1.57	1.27	1.09	1.36	1.27	2.04
2.75	2.14	1.78	1.29	1.17	1.35	1.30	2.14
3.00	2.00	1.54	1.20	1.00	1.34	1.20	1.87
3.25	1.96	1.23	1.32	1.06	1.06	1.37	1.94
3.50	2.07	1.21	1.41	1.06	1.23	1.26	1.89
3.75	1.73	1.19	1.13	1.11	0.98	1.14	1.82
4.00	1.79	1.20	1.23	0.96	1.18	1.16	1.67
4.25	1.67	1.18	1.11	0.93	1.02	1.13	1.59
4.50	1.69	1.30	1.04	1.01	0.98	1.18	1.67
4.75	1.52	1.04	0.98	0.98	1.17	1.14	1.42
5.00	1.35	1.41	1.28	1.42	1.13	1.18	1.54
5.25	1.54	1.39	1.28	1.35	1.39	1.45	1.52
5.50	1.46	1.54	1.58	1.35	1.54	1.44	1.57
5.75	1.56	1.72	1.82	1.79	1.70	1.76	1.77
6.00	1.66	2.45	2.23	2.29	2.15	2.26	1.92
6.25	1.71	2.32	2.44	2.42	2.09	2.47	2.05
6.50	2.09	2.85	2.90	2.66	2.71	2.68	2.42
6.75	2.31	3.55	2.97	2.68	2.98	2.72	2.46
7.00	2.71	4.48	4.19	4.07	3.97	3.95	2.85
7.25	2.70	4.89	4.18	4.11	3.73	3.76	2.84
7.50	2.66	5.40	4.78	4.12	4.18	4.14	3.37
7.75	2.96	5.89	5.19	4.47	4.11	4.46	3.14
8.00	3.52	7.53	5.67	5.14	4.68	5.07	4.18
8.25	3.33	7.49	6.44	5.00	5.24	5.37	4.23
8.50	3.87	9.04	6.93	5.64	5.45	5.96	4.41
8.75	3.92	10.40	7.37	5.52	5.74	6.25	4.08
9.00	3.89	11.26	7.91	6.57	6.67	6.80	4.85
9.25	4.41	12.36	9.65	6.52	6.50	7.25	4.77
9.50	4.43	11.86	8.72	7.41	6.41	7.75	4.29
9.75	4.54	10.88	8.82	6.34	6.34	6.82	5.21
10.00	4.90	10.39	8.92	6.90	6.17	6.54	5.20
10.25	4.94	9.90	8.97	6.09	6.13	5.89	5.18
10.50	5.22	9.25	8.51	6.06	6.01	6.18	4.59
10.75	4.60	8.69	7.80	6.10	5.88	5.83	5.19
11.00	4.68	8.76	7.33	6.18	6.14	6.51	5.16
11.25	4.34	8.30	7.73	6.02	5.58	5.99	4.80
11.50	4.46	7.85	7.39	6.14	5.74	5.72	4.64
11.75	4.38	8.38	6.64	6.67	5.49	5.85	4.34
12.00	4.36	7.73	6.94	6.22	6.25	5.63	4.70

Continued on next page

Table A.2 – continued from previous page

Decimal time	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
12.25	4.79	8.04	6.57	5.58	6.57	5.53	4.82
12.50	4.81	7.50	7.12	5.93	5.65	5.61	4.98
12.75	4.78	7.30	6.44	5.44	5.46	5.75	4.65
13.00	4.35	7.35	7.58	5.86	6.17	5.76	4.73
13.25	4.10	7.13	6.72	5.45	5.75	5.86	4.64
13.50	4.28	7.58	6.80	5.54	5.24	5.44	4.59
13.75	3.98	7.07	6.97	5.12	5.55	5.49	4.12
14.00	4.63	7.77	6.84	5.76	5.93	6.26	4.37
14.25	4.11	7.77	7.23	5.51	5.96	6.10	4.23
14.50	4.57	7.64	6.68	5.75	5.58	5.52	3.90
14.75	3.65	7.36	7.28	5.93	5.46	5.84	4.20
15.00	4.09	7.89	7.58	6.24	5.82	6.28	4.75
15.25	4.17	7.61	7.17	6.25	5.00	6.05	4.67
15.50	4.19	7.86	7.03	6.09	5.96	6.42	4.29
15.75	4.16	8.26	6.99	5.76	5.44	6.29	4.13
16.00	4.20	7.79	6.75	6.25	5.98	6.80	4.24
16.25	4.05	7.90	7.03	6.03	5.71	6.55	4.17
16.50	4.20	7.94	6.45	6.45	6.40	6.30	4.13
16.75	4.47	7.40	6.56	6.22	6.48	5.78	4.16
17.00	4.43	7.32	6.27	5.05	6.32	6.03	4.37
17.25	4.18	6.26	5.89	5.32	5.20	6.00	4.36
17.50	4.08	5.99	5.87	5.33	4.87	5.49	4.38
17.75	3.98	5.99	5.16	4.80	5.12	5.17	4.07
18.00	3.92	5.69	5.49	4.55	4.85	5.06	4.14
18.25	4.04	5.72	5.38	4.54	4.78	4.64	4.37
18.50	4.07	5.54	5.03	5.34	4.57	5.20	3.68
18.75	3.92	4.98	4.93	4.47	4.40	5.14	3.68
19.00	4.04	4.82	4.63	4.90	4.37	4.85	4.19
19.25	4.11	4.33	4.46	4.34	4.21	4.43	3.66
19.50	3.64	4.23	4.17	4.17	4.00	4.15	3.70
19.75	3.82	4.54	3.99	3.79	3.55	4.23	3.56
20.00	3.50	4.43	4.30	3.92	3.85	4.15	3.38
20.25	3.91	4.07	4.22	3.99	3.59	3.93	3.78
20.50	3.32	3.76	3.90	4.11	3.61	3.77	3.08
20.75	3.51	3.36	3.67	3.32	3.82	3.44	3.37
21.00	3.76	3.58	3.67	3.56	3.43	3.45	3.26
21.25	3.31	3.43	3.52	3.79	3.23	3.27	2.79
21.50	3.21	3.36	3.20	3.34	3.61	3.31	3.29
21.75	2.92	3.07	3.01	3.13	3.45	3.35	3.12
22.00	3.12	3.08	2.93	3.03	3.32	3.43	3.23
22.25	3.25	2.94	3.12	3.17	3.62	3.61	3.33
22.50	2.94	2.86	2.77	2.84	3.06	3.64	2.89
22.75	2.84	2.59	2.84	2.54	2.67	2.97	2.95
23.00	2.81	2.48	2.67	2.56	2.85	3.04	3.12
23.25	2.82	2.41	2.62	2.75	2.88	2.76	2.94
23.50	2.72	2.07	2.15	2.48	2.65	3.04	3.06
23.75	2.27	2.12	1.98	2.07	2.20	2.79	2.67

A.3 Historical urgent queue summary means

Table A.3: Urgent queue means of calls received by quarter hour for the period January 2005 to December 2008

Decimal time	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
0.00	48.75	18.46	15.65	16.68	19.66	22.04	45.06
0.25	44.03	16.12	14.30	14.62	17.28	19.84	41.36
0.50	43.41	14.75	12.04	13.15	15.71	18.33	37.65
0.75	41.60	13.41	11.18	12.17	14.46	16.76	36.39
1.00	39.38	12.31	10.46	11.06	13.93	16.32	35.37
1.25	37.64	11.27	9.63	10.35	12.49	14.72	33.40
1.50	35.07	10.38	8.71	9.54	11.28	13.82	32.23
1.75	32.25	9.72	7.76	8.99	10.26	12.50	29.64
2.00	31.89	8.73	7.32	7.72	9.64	12.08	28.34
2.25	29.32	8.07	6.94	7.83	9.39	11.25	26.67
2.50	27.57	7.23	6.55	6.52	8.76	10.77	25.65
2.75	25.78	6.73	5.96	5.83	8.30	10.12	23.74
3.00	24.97	6.31	5.80	5.64	7.53	9.82	22.45
3.25	23.08	6.52	5.24	5.36	6.99	9.19	20.79
3.50	20.82	5.57	5.03	4.83	6.61	7.92	19.25
3.75	18.38	5.29	4.71	4.49	5.95	7.13	16.53
4.00	16.31	4.91	4.10	4.59	5.45	6.92	15.19
4.25	14.80	4.52	4.16	4.24	4.84	6.46	13.67
4.50	13.45	4.13	3.79	3.86	4.49	5.61	12.33
4.75	11.93	4.20	3.71	3.78	4.41	5.30	11.00
5.00	10.57	4.06	3.53	3.71	4.19	4.86	10.26
5.25	9.07	4.08	3.50	3.52	3.94	4.80	8.80
5.50	8.57	3.94	4.18	3.74	4.45	4.83	7.70
5.75	8.10	4.50	4.28	4.35	4.62	5.21	7.47
6.00	7.56	5.07	4.86	4.64	4.77	5.56	6.94
6.25	7.53	5.43	5.23	5.49	5.58	6.07	7.56
6.50	7.18	5.99	6.02	5.78	6.16	6.71	7.43
6.75	7.18	6.92	6.72	6.76	7.25	7.28	7.90
7.00	7.46	7.48	7.51	7.61	7.85	8.43	7.97
7.25	7.69	8.55	9.03	8.24	8.75	8.89	8.35
7.50	8.24	8.88	9.31	9.75	9.40	9.47	8.96
7.75	8.37	10.20	10.85	9.69	10.48	10.30	9.58
8.00	9.59	11.51	12.27	11.15	11.77	11.65	10.65
8.25	9.44	12.27	12.81	12.35	12.66	12.11	11.10
8.50	10.52	13.04	13.45	12.77	12.58	12.97	12.07
8.75	11.23	13.37	13.69	12.61	12.74	12.82	12.79
9.00	12.57	13.70	12.80	12.97	13.09	13.29	13.62
9.25	13.21	13.29	12.85	12.81	12.16	12.80	14.48
9.50	13.57	13.17	12.61	12.73	12.91	12.82	15.30
9.75	15.52	13.50	13.14	12.62	12.75	12.84	15.73
10.00	15.62	13.99	12.76	13.25	13.52	13.45	17.76
10.25	15.85	14.39	13.50	13.70	13.38	13.61	17.88
10.50	16.38	14.62	13.38	13.46	13.30	14.36	17.81
10.75	17.82	15.00	14.10	14.08	13.73	15.17	18.37
11.00	17.65	15.75	14.43	14.22	14.21	15.62	20.11
11.25	18.42	16.13	14.64	14.51	14.51	15.60	19.96
11.50	18.74	16.02	14.73	14.29	13.72	16.31	20.47
11.75	19.73	15.60	14.38	14.52	14.45	16.01	20.35
12.00	19.09	16.34	15.33	14.93	15.12	16.14	21.18

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Table A.3 – continued from previous page

Decimal time	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
12.25	19.49	16.41	15.56	15.89	16.35	16.95	21.41
12.50	21.09	17.14	15.95	16.38	15.48	17.42	21.87
12.75	20.86	18.20	16.48	16.50	16.01	17.61	21.38
13.00	20.94	17.70	16.81	16.83	16.92	17.61	22.04
13.25	20.87	17.68	16.55	17.23	17.17	18.58	22.11
13.50	21.50	18.19	17.54	17.37	17.75	19.08	21.68
13.75	20.76	17.96	17.51	17.36	17.22	18.90	21.64
14.00	22.24	18.63	17.49	18.05	17.88	19.90	22.84
14.25	21.43	19.04	17.93	17.99	17.96	20.06	22.82
14.50	22.10	19.67	18.41	18.80	19.51	20.32	22.73
14.75	22.35	20.14	19.73	19.24	20.18	21.32	23.98
15.00	23.17	22.39	21.89	22.24	21.71	23.52	24.51
15.25	23.54	24.53	23.37	23.42	24.27	26.08	23.61
15.50	23.12	24.69	22.96	24.78	24.25	26.07	24.16
15.75	24.13	24.68	23.84	24.18	25.38	25.96	23.75
16.00	24.60	25.32	24.88	24.44	25.50	26.76	24.59
16.25	24.85	24.49	25.32	25.40	25.41	26.26	25.03
16.50	25.14	24.89	24.84	25.58	25.65	27.17	25.59
16.75	26.19	26.21	25.61	26.09	25.67	27.40	25.92
17.00	26.21	27.23	26.88	26.30	26.33	28.72	27.49
17.25	26.22	26.97	27.42	28.23	26.76	28.84	26.78
17.50	26.23	27.43	28.11	28.10	27.86	29.65	27.47
17.75	25.45	27.53	27.62	27.21	26.98	28.57	27.62
18.00	26.86	27.51	28.23	28.60	28.03	30.25	28.00
18.25	26.93	28.28	27.32	27.90	26.90	29.33	28.22
18.50	26.27	26.61	26.53	27.10	26.78	29.65	26.90
18.75	26.05	26.38	27.03	27.72	26.70	30.27	27.83
19.00	27.04	25.90	26.23	26.29	26.55	29.31	27.62
19.25	25.29	25.18	24.41	25.71	26.01	28.47	27.11
19.50	25.12	24.33	25.12	25.16	26.28	29.49	28.00
19.75	25.12	24.71	24.92	25.47	25.63	28.40	28.22
20.00	26.31	24.57	24.33	25.45	25.73	28.23	28.27
20.25	25.67	24.56	24.86	24.42	26.06	28.26	28.34
20.50	26.23	24.22	25.19	24.56	26.19	29.49	29.41
20.75	26.34	24.45	25.21	25.50	27.09	30.54	30.20
21.00	26.38	23.56	24.26	25.30	27.42	31.77	30.98
21.25	26.11	23.47	24.53	24.44	27.90	32.31	33.11
21.50	25.30	23.59	24.85	25.13	28.40	33.74	34.19
21.75	25.49	22.68	24.15	24.33	27.14	35.05	36.21
22.00	25.80	23.61	22.98	24.57	27.07	36.75	38.28
22.25	24.06	22.45	22.84	23.46	26.54	37.80	38.68
22.50	23.18	21.44	20.38	24.06	24.87	37.34	38.11
22.75	22.49	20.23	20.93	21.87	25.00	37.65	40.24
23.00	21.26	18.77	19.63	22.23	24.03	40.68	40.70
23.25	20.13	17.94	18.52	20.64	23.15	40.42	42.36
23.50	18.61	16.42	17.70	20.22	22.41	40.40	42.06
23.75	16.53	14.22	14.30	17.63	19.53	37.16	38.75

A.4 *Historical urgent queue summary SDs*

Table A.4: Urgent queue Standard Deviations of calls received by quarter hour for the period January 2005 to December 2008

Decimal time	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
0.00	18.20	10.47	9.61	7.96	9.44	11.15	18.06
0.25	16.34	11.06	9.79	7.94	8.78	10.29	15.83
0.50	16.79	9.43	8.50	6.74	8.95	9.30	14.81
0.75	16.69	9.19	8.23	6.43	7.38	9.04	14.68
1.00	15.46	9.01	7.54	6.26	7.57	8.75	14.53
1.25	15.02	8.36	7.22	6.04	6.68	7.90	14.16
1.50	13.67	9.19	7.89	6.02	6.55	6.77	13.50
1.75	13.30	8.69	6.49	5.29	5.86	6.95	12.74
2.00	13.28	8.10	5.96	4.56	5.32	6.65	12.00
2.25	12.48	6.56	5.68	4.93	5.20	6.40	11.27
2.50	11.59	7.05	6.03	4.27	4.67	5.74	10.82
2.75	11.07	5.89	5.38	3.61	4.74	5.59	10.24
3.00	10.97	6.63	5.89	3.31	4.61	5.89	9.05
3.25	9.49	8.56	6.54	3.51	4.39	5.71	10.09
3.50	8.43	7.62	6.66	3.10	3.88	4.81	8.83
3.75	7.67	7.86	5.04	2.96	4.05	4.14	7.36
4.00	6.75	6.71	4.68	3.44	3.88	4.10	7.35
4.25	6.69	5.96	3.98	3.33	3.36	3.90	6.95
4.50	6.68	4.27	3.54	2.66	2.84	3.52	5.97
4.75	5.96	3.57	3.57	2.51	2.56	3.07	5.22
5.00	5.38	3.05	3.60	2.33	2.52	2.85	5.03
5.25	4.31	2.72	3.47	2.64	2.48	2.95	4.63
5.50	3.98	3.01	3.27	2.43	2.70	2.84	4.21
5.75	4.47	2.59	3.34	2.68	2.52	2.86	3.65
6.00	3.73	2.97	3.39	2.66	2.74	3.13	3.42
6.25	3.87	2.97	3.88	2.87	3.00	3.47	4.20
6.50	3.81	3.31	3.92	2.88	3.34	3.33	3.84
6.75	3.47	3.42	3.72	3.15	3.69	3.55	4.48
7.00	3.54	3.49	3.65	3.58	3.98	3.80	4.33
7.25	3.98	3.93	4.36	3.80	3.94	4.11	4.13
7.50	3.90	4.03	4.88	4.32	4.32	3.96	4.50
7.75	3.75	4.80	4.99	4.18	4.51	4.31	4.38
8.00	4.36	5.35	5.83	4.87	5.17	4.94	5.11
8.25	4.48	4.96	6.29	5.18	5.40	5.40	4.79
8.50	4.81	5.11	6.78	5.54	4.62	5.02	5.12
8.75	4.47	5.77	6.18	5.35	5.18	4.97	5.62
9.00	5.62	6.19	4.57	5.13	5.15	5.55	6.00
9.25	5.53	5.55	5.01	4.96	4.67	5.13	5.64
9.50	5.88	4.99	4.58	5.09	4.83	5.47	6.77
9.75	6.08	5.22	5.16	4.75	5.00	5.42	6.16
10.00	6.42	5.29	4.85	5.34	5.69	5.40	6.95
10.25	6.07	6.74	5.44	5.43	5.08	5.41	7.07
10.50	6.78	5.86	5.48	5.45	5.45	5.80	6.20
10.75	7.67	5.57	5.21	5.55	4.96	5.95	7.14
11.00	7.12	6.20	6.11	5.63	5.46	6.46	7.43
11.25	6.82	6.08	5.62	5.26	5.64	6.46	7.15
11.50	7.55	6.13	5.81	5.40	5.73	6.44	7.61
11.75	7.61	6.05	6.52	5.40	5.23	5.85	7.97
12.00	7.06	6.03	5.67	5.83	5.60	6.35	7.46

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Table A.4 – continued from previous page

Decimal time	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
12.25	7.32	5.76	6.46	6.22	6.51	6.04	8.23
12.50	8.13	5.94	7.51	6.56	6.07	6.36	8.34
12.75	8.41	7.65	7.41	6.51	5.97	6.85	7.76
13.00	7.76	6.90	7.70	6.33	5.99	7.14	7.90
13.25	7.93	6.14	6.91	6.24	6.31	6.76	7.87
13.50	7.80	6.81	7.35	6.33	6.68	7.19	7.79
13.75	7.88	6.27	7.75	6.62	6.15	6.95	8.15
14.00	8.78	7.04	7.80	6.91	6.30	8.01	9.22
14.25	8.29	6.78	6.33	6.41	7.01	8.57	8.72
14.50	8.51	6.99	6.98	6.61	6.87	7.78	8.57
14.75	8.92	7.13	7.23	7.03	7.00	8.36	8.76
15.00	8.80	7.57	7.49	7.70	7.51	8.61	9.02
15.25	8.26	7.90	7.77	7.66	8.34	9.74	8.44
15.50	8.75	7.88	8.19	8.41	7.57	9.09	8.72
15.75	8.82	8.61	8.11	8.74	8.67	9.13	8.15
16.00	9.21	8.77	8.79	8.64	8.18	9.25	9.58
16.25	9.18	8.06	8.89	10.60	8.36	9.80	8.65
16.50	10.75	7.99	8.46	9.67	8.20	9.77	8.79
16.75	9.99	9.38	9.04	8.83	9.02	10.06	9.52
17.00	9.52	9.66	10.02	9.41	9.34	10.14	9.23
17.25	8.77	9.17	9.22	11.61	9.39	9.98	9.13
17.50	9.30	9.65	9.40	10.74	9.46	10.24	9.89
17.75	8.83	8.63	10.26	9.80	8.40	10.34	9.45
18.00	9.45	9.67	10.27	10.09	8.86	11.03	9.63
18.25	9.39	10.21	9.31	10.24	9.42	10.15	9.85
18.50	8.59	9.73	9.53	9.12	9.41	11.35	9.34
18.75	9.13	9.74	9.17	9.93	9.81	12.63	9.72
19.00	9.66	9.25	9.56	9.57	9.59	12.48	10.32
19.25	10.53	9.15	8.57	9.49	9.13	10.60	9.18
19.50	9.54	8.67	8.65	9.22	8.71	10.69	10.64
19.75	9.48	8.73	9.20	9.63	9.16	10.13	11.00
20.00	10.26	9.26	9.75	9.74	8.88	10.43	10.77
20.25	9.88	8.85	9.69	9.39	9.34	10.55	10.15
20.50	9.87	9.30	10.17	9.44	9.70	11.18	10.84
20.75	11.78	9.48	10.88	9.47	9.93	11.25	10.83
21.00	10.01	9.65	10.15	9.74	10.19	12.01	11.96
21.25	10.25	9.18	10.35	10.06	10.81	12.49	11.73
21.50	10.52	9.03	10.45	9.93	11.33	13.42	12.10
21.75	9.81	9.62	10.96	9.42	10.59	13.51	12.20
22.00	9.98	12.06	10.25	10.44	10.69	14.25	13.31
22.25	10.87	11.65	9.55	10.33	11.21	15.24	14.82
22.50	9.81	13.75	9.10	10.45	10.53	15.40	14.24
22.75	10.47	10.20	9.46	10.18	11.24	14.50	14.02
23.00	10.67	9.02	9.02	11.01	10.62	15.49	14.70
23.25	10.75	10.26	9.07	10.21	10.43	15.64	15.58
23.50	9.81	8.92	8.76	11.20	10.76	16.28	16.09
23.75	9.09	8.60	6.72	9.45	8.87	15.36	13.98

Appendix B

JULY 2007 EXOGENOUS EVENT DATA

B.1 Urgent queue data for 6 and 7 July 2007

Table B.1: Urgent queue call data by quarter hour blocks for the period 6 pm 6 July 2007 to 6 am 7 July 2007

Date	Time (hh:mm)	No. calls entered	No. calls calls answered	No. Answered <10 seconds	No. calls Abandoned	Max. time to answer (mm:ss)	Max. time to abandon (mm:ss)	ASA (mm:ss)	Service factor %
6	18:00	31	22	11	9	1.07	1.57	0.19	50
6	18:15	28	26	23	2	0.26	0.45	0.07	88
6	18:30	31	31	29	0	0.1	0	0.05	94
6	18:45	28	27	25	1	0.39	0.26	0.06	93
6	19:00	25	25	25	0	0.08	0	0.04	100
6	19:15	22	22	22	0	0.09	0	0.05	100
6	19:30	27	27	27	0	0.08	0	0.05	100
6	19:45	30	30	29	0	0.1	0	0.05	97
6	20:00	34	23	17	11	0.39	1.58	0.11	74
6	20:15	32	32	29	0	1.24	0	0.08	91
6	20:30	46	45	45	1	0.08	0.04	0.04	100
6	20:45	27	27	27	0	0.09	0	0.05	100
6	21:00	35	34	33	1	0.1	0	0.05	97
6	21:15	25	25	25	0	0.08	0	0.04	100
6	21:30	33	33	33	0	0.08	0	0.05	100
6	21:45	40	32	29	8	0.43	0.55	0.08	91
6	22:00	34	22	12	12	1.23	1.58	0.18	55
6	22:15	39	25	15	14	1.53	1.17	0.25	60
6	22:30	37	37	26	0	0.53	0	0.12	70
6	22:45	66	2	0	64	1.34	1.58	0.58	0
6	23:00	75	0	0	75	0	1.58	0	0
6	23:15	79	3	0	76	1.45	1.58	1.15	0
6	23:30	54	2	1	52	0.51	1.59	0.28	50
6	23:45	38	32	28	6	0.47	0.53	0.07	88
7	0:00	56	42	5	14	1.06	1.57	0.25	12
7	0:15	45	14	0	31	1.06	1.58	0.31	0
7	0:30	31	27	21	4	0.35	0.59	0.1	78
7	0:45	38	27	16	11	0.44	1.58	0.15	59
7	1:00	34	30	13	4	1.53	0.47	0.24	43

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Table B.1 – continued from previous page

Date	Time (hh:mm)	No. calls entered	No. calls calls answered	No. Answered <10 seconds	No. calls Abandoned	Max. time to answer (mm:ss)	Max. time to abandon (mm:ss)	ASA (mm:ss)	Service factor %
7	1:15	33	29	22	4	0.44	0.58	0.12	76
7	1:30	37	22	11	15	0.44	0.55	0.16	50
7	1:45	16	16	16	0	0.08	0	0.05	100
7	2:00	17	17	15	0	0.47	0	0.1	88
7	2:15	16	14	12	2	0.55	0.46	0.1	86
7	2:30	24	21	13	3	1.1	1.58	0.16	62
7	2:45	20	8	3	12	1.57	1.58	0.31	38
7	3:00	32	1	1	31	0.04	1.58	0.04	100
7	3:15	30	14	6	16	1.53	1.58	0.32	43
7	3:30	23	18	10	5	0.42	0.47	0.16	56
7	3:45	13	13	12	0	0.13	0	0.06	92
7	4:00	17	16	11	1	1.11	0.48	0.17	69
7	4:15	9	9	9	0	0.07	0	0.06	100
7	4:30	17	17	16	0	0.21	0	0.07	94
7	4:45	17	11	8	6	0.44	0.58	0.14	73
7	5:00	21	9	6	12	0.44	1.59	0.15	67
7	5:15	11	11	11	0	0.08	0	0.06	100
7	5:30	3	3	3	0	0.09	0	0.07	100
7	5:45	5	5	5	0	0.07	0	0.06	100

B.2 Non-urgent queue data for 6 and 7 July 2007

Table B.2: Non-urgent queue call data by quarter hour blocks for the period 6 pm 6 July 2007 to 6 am 7 July 2007

Date	Time (hh:mm)	No. calls entered	No. calls calls answered	No. Answered <10 seconds	No. calls Abandoned	Max. time to answer (mm:ss)	Max. time to abandon (mm:ss)	ASA (mm:ss)	Service factor %
6/07/11	18:00 - 18:15	21	18	8	3	5.21	5	1.43	44
6/07/11	18:15 - 18:30	18	18	18	0	0.14	0	0.05	100
6/07/11	18:30 - 18:45	15	15	15	0	0.09	0	0.05	100
6/07/11	18:45 - 19:00	22	17	10	5	5.06	3.03	1.1	59
6/07/11	19:00 - 19:15	20	17	12	3	3.3	0.25	0.4	71
6/07/11	19:15 - 19:30	18	14	4	4	8.3	2.03	2.33	29
6/07/11	19:30 - 19:45	22	17	4	5	8.28	11.51	3.44	24
6/07/11	19:45 - 20:00	11	11	11	0	0.16	0	0.07	100
6/07/11	20:00 - 20:15	15	14	12	1	1.03	0.11	0.17	86
6/07/11	20:15 - 20:30	17	17	17	0	0.09	0	0.05	100
6/07/11	20:30 - 20:45	10	10	10	0	0.1	0	0.06	100
6/07/11	20:45 - 21:00	13	13	13	0	0.09	0	0.06	100
6/07/11	21:00 - 21:15	15	14	11	1	1.56	0	0.28	79
6/07/11	21:15 - 21:30	11	11	11	0	0.15	0	0.07	100
6/07/11	21:30 - 21:45	13	13	13	0	0.09	0	0.05	100
6/07/11	21:45 - 22:00	11	11	11	0	0.14	0	0.06	100
6/07/11	22:00 - 22:15	11	11	11	0	0.16	0	0.07	100
6/07/11	22:15 - 22:30	7	7	7	0	0.07	0	0.05	100
6/07/11	22:30 - 22:45	9	9	9	0	0.08	0	0.06	100
6/07/11	22:45 - 23:00	10	10	9	0	1.02	0	0.15	90
6/07/11	23:00 - 23:15	8	8	8	0	0.09	0	0.06	100
6/07/11	23:15 - 23:30	6	6	6	0	0.05	0	0.04	100
6/07/11	23:30 - 23:45	8	8	8	0	0.1	0	0.06	100
6/07/11	23:45 - 00:00	2	2	2	0	0.14	0	0.09	100
7/07/11	00:00 - 00:15	4	4	4	0	0.09	0	0.07	100
7/07/11	00:15 - 00:30	2	2	2	0	0.09	0	0.08	100
7/07/11	00:30 - 00:45	5	5	5	0	0.08	0	0.05	100
7/07/11	00:45 - 01:00	3	3	3	0	0.06	0	0.05	100

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Table B.2 – continued from previous page

Date	Time (hh:mm)	No. calls entered	No. calls calls answered	No. Answered <10 seconds	No. calls Abandoned	Max. time to answer (mm:ss)	Max. time to abandon (mm:ss)	ASA (mm:ss)	Service factor %
7/07/11	01:00 - 01:15	9	9	6	0	3.05	0	0.44	67
7/07/11	01:15 - 01:30	7	7	2	0	4.45	0	1.44	29
7/07/11	01:30 - 01:45	3	3	3	0	0.04	0	0.04	100
7/07/11	01:45 - 02:00	3	3	3	0	0.07	0	0.05	100
7/07/11	02:00 - 02:15	4	3	1	1	1.28	0.13	0.59	33
7/07/11	02:15 - 02:30	5	5	3	0	2.11	0	0.53	60
7/07/11	02:30 - 02:45	5	4	4	1	0.15	2.18	0.1	100
7/07/11	02:45 - 03:00	3	2	1	1	1.03	0.08	0.36	50
7/07/11	03:00 - 03:15	5	5	4	0	1.51	0	0.26	80
7/07/11	03:15-03:30	0	0	0	0	0	0	0	100
7/07/11	03:30 - 03:45	3	3	3	0	0.07	0	0.05	100
7/07/11	03:45 - 04:00	1	1	1	0	0.03	0	0.03	100
7/07/11	04:00 - 04:15	1	1	1	0	0.06	0	0.06	100
7/07/11	04:15 - 04:30	1	1	1	0	0.04	0	0.04	100
7/07/11	04:30 - 04:45	1	1	1	0	0.09	0	0.09	100
7/07/11	04:45 - 05:00	2	2	2	0	0.07	0	0.07	100
7/07/11	05:00 - 05:15	1	1	1	0	0.03	0	0.03	100
7/07/11	05:15 - 05:30	2	2	2	0	0.06	0	0.06	100
7/07/11	05:30 - 05:45	2	2	2	0	0.05	0	0.05	100
7/07/11	05:45 - 06:00	2	2	2	0	0.06	0	0.06	100

Appendix C

RESOURCES

This appendix contains the resources used by the researcher to undertake the research and to prepare this thesis.

Hardware platform:	Apple MacBook4,1, Intel Core 2 Duo
Operating system:	Mac OS X, Version 10.6.4
Model programming, statistics and plotting	MATLAB®Version 2008a http://www.mathworks.com/
Thesis document preparation:	LaTeX http://www.latex-project.org/
Virtual machine:	Parallels® Desktop 5 for Mac
Data preparation:	Microsoft® Excel with Visual Basic for Applications (VBA) running from Parallels®

All MATLAB®programs and Microsoft® VBA software code was written by the researcher, Bruce Lewis.

Appendix D

MODEL SOURCE CODE

The source code for the agent-based model is contained in media that accompanies this thesis.

Except for the preceding appendices NSWPAL data has not been included.