IMPLEMENTATION OF SIMULATION FOR NETWORK SERVICE DELIVERY POINT CAPACITY ANALYSIS

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of the requirements for the degree of
Master of Science in Engineering

By

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ABSTRACT

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As businesses consolidate and modernize their operations, the impact on their network and computing infrastructure is a major consideration. In this thesis, discrete event simulation is used to show how implementation of an Enterprise Resource Planning (ERP) system can impact network performance and ultimately affect end-users. More specifically, the model simulates the flow of data packets across a network, through a Service Delivery Point (SDP), which is comprised of routers, switches, and firewalls that connect a Local Area Network to a Wide Area Network.

The model was used to run to determine the affect of more network traffic and additional SDP bandwidth capacity on end-user response time, which is the time for a transaction to be processed and returned to the user. Analysis of model output concluded that a 10%, 20%, and 30% increase in network traffic results in a 98%, 209%, and 352% increase in end-user response time, relative to the current workload. Further experimentation with the model concluded that a 42.5% increase in SDP bandwidth capacity reduced the average response time by 75%. By estimating end-user response time, proper SDP capacity can be planned prior to ERP deployment, to ensure timely completion of end-user transactions that inevitably affects bottom line cost.

Table of Contents

1 Introduction 1
2 Background 4
2.1 Air Force ERP Vision 4
2.2 Problem Statement 7
3 Literature Review 8
3.1 ERP Implementation 8
3.2 Modeling and Simulation for ERPs 12
3.2.1 Integration of ERP Data with Simulation 12
3.2.2 ERP Architecture Modeling 13
3.2.3 Simulation of IT Infrastructure 14
4 Model Development 19
4.1 Discrete Event Simulation 19
4.2 ExtendSim® Software 20
4.3 The Model 20
4.3.1 Overview 20
4.3.2 Assumptions 22
4.3.3 Input Data 24
4.3.4 Output Data 27
4.3.5 Verification 28
4.3.6 Validation 29
5 Analysis 30
6 Discussion and Further Study 37
Appendix A: DoD ERP Systems 39
Appendix B: Acronym List 40
Appendix C: Averaged SDP Throughput Charts 41
Appendix D: Filler Traffic Input Data 43
Appendix E: Theoretical Utilization and Simulation Utilization Charts 48
Appendix F: Single Simulation Run Response Time Output 52
Appendix G: Excel VBA Code 54
Appendix H: Hourly Average Response Time Charts 59
Appendix I: Five Minute Average Response Time Charts 67
Appendix J: Utilization vs. Response Time Charts 75
References 83

List of Figures

Figure 1 – Air Force As-Is Logistics Architecture (USDoD, 2005) 6
Figure 2 – Air Force To-Be Logistics Architecture (USDoD, 2005) 6
Figure 3 – Conceptual Model 21
Figure 4 – Top Hierarchical View of Model (Fitzgerald & Harper, 2008) 22
Figure 5 – Base Y SDP Original Data (NovaTech work source) 26
Figure 6 – Base X SDP Original Data (NovaTech work source) 26
Figure 7 – Base X Averaged Incoming SDP Data 27
Figure 8 – Example Theoretical Utilization and Simulation Output Utilization Plot 29
Figure 9 – Current Workload 1 Hour Average Response Times 31
Figure 10 – Current Workload Five Minute Average Response Times 32
Figure 11 – Current Workload 1 Hour Response Time Coefficient of Variance 32
Figure 12 – Current Workload Five Minute Response Time Coefficient of Variance 32
Figure 13 – Example Response Time vs. SDP Utilization Plot 33

List of Tables

Table 1 – Qualitative CSFs 11
Table 2 – Input Data for Model Delays 24
Table 3 – Experiment 1 Design 30
Table 4 – Experiment 2 Design 31
Table 5 – Total Day Average Response Times for Workload Experiment 34
Table 6 – Peak 3 Hours Average Response Times for Workload Experiment 34
Table 7 – Peak 1 Hour Average Response Times for Workload Experiment 34
Table 8 – Maximum Response Times (sec) for Workload Experiment 35
Table 9 – SDP Utilization Results 35
Table 10 – Peak 1 Hour Average Response Times for Capacity Experiment 36
Table 11 – Maximum Response Time (sec) for Capacity Experiment 36

1 Introduction

The United States Air Force, in accordance with the Department of Defense's mission to modernize its processes, systems, and information flows, began an effort to replace legacy systems with two Enterprise Resource Planning (ERP) systems (USDoD, 2007a). Nova Technology Solutions (NovaTech), an Information Technology (IT) and Analytics firm, recognized the Air Force's need for a repeatable, reliable, tool to aid decision-making during the planning, installation, and sustainment of these ERP systems, thus proposing the use of modeling and simulation. Since it is also costly and time consuming to experiment with real world systems, modeling and simulation provides a risk free and relatively cheap tool for what-if analyses. To demonstrate how modeling and simulation could be utilized, a simple simulation model was built to analyze the impact of ERP increased workload on network performance, specifically at the Air Force Service Delivery Points (SDPs). Many of the concepts and work in this thesis come from work completed with NovaTech and a subsequent paper published in the 2008 Winter Simulation Conference (Fitzgerald & Harper, 2008).

A Service Delivery Point (SDP) is defined as "the physical, electrical and service interface between the contractor's network and the government premise equipment, off premises switching and transmission equipment, and other facilities (AT&T, 2008)." More specifically, an SDP is a combination of routers, switches, and firewalls that resides

at each USAF base to securely connect the bases' Local Area Network (LAN) to the Wide Area Network (WAN). Each SDP is configured for a maximum of 100 MBps bandwidth capacity, but due to budgeting the SDPs are setup as needed. Many bases currently face saturation at 95% during peak hours causing a bottleneck in the communication network. The implementation of the AF ERP systems is expected to cause an increase in traffic through the SDPs. Thus, it is necessary to analyze the capability of each SDP to determine how the increased traffic will affect Air Force (AF) end-users. (Fitzgerald & Harper, 2008)

To analyze the impact of increased ERP workload on SDP performance and end-user response time, a discrete event simulation model was used to simulate the flow of data packets across the AF communications network. Conceptually, an end-user working on a base will generate a transaction that must be processed by a server stationed at another base. Therefore, the end-user's response time is determined by the time it takes for all of the transaction's data packets to travel through the AF communications network to the server and return to the end-user's computer. While the original NovaTech model assumes each SDP has a single resource servicing the combined inbound and outbound traffic, the model used for this thesis assumes there are two resources, one for inbound traffic and one for outbound traffic. Results from the original model show that a 15% increase in current workload, or current network traffic, will cause a 250% increase in end-user response time (Fitzgerald & Harper, 2008), while the model used for this thesis showed a 98%, 209%, and 352% increase in response time when the current workload is increased by 10%, 20%, and 30%, respectively. In an experiment investigating the impact of capacity expansion in the model with the double resource SDP, it was determined that

for a 30% increased workload a 42.5% increase in SDP bandwidth capacity at the base hosting the application server resulted in a 75% decrease in average end-user response time during the peak traffic hour.

The remainder of this document is organized as follows: Chapter 2 has background information relevant to the project objective. Chapter 3 has a literature review. Chapter 4 describes the model details and development. Chapter 5 details the analysis and experiment results. Conclusions and potential future work is summarized in Chapter 6.

2 Background

2.1 Air Force ERP Vision

The United States Department of Defense (DoD) initiated the Enterprise Transition Plan (ETP) in September 2005 to modernize the processes, systems, and information flows within the DoD to support 21st Century national security requirements (USDoD, 2007a). Part of the ETP is the implementation of 12 Enterprise Resource Planning (ERP) systems throughout the DoD (refer to Appendix A). Although these ERP systems only make up 12 out of 102 initiatives in the ETP, they account for more than 50% of the Department's annual investment in business systems modernization. Of the 12 ERP systems, the Air Force will be implementing the Expeditionary Combat Support System (ECSS) and the Defense Enterprise Accounting and Management System (DEAMS) (USDoD, 2007a).

ERP systems are a suite of integrated business modules that utilize a common database to execute end-to-end processes (USDoD, 2007a). These systems integrate application programs in accounting, sales, manufacturing, and the other functions in a firm, by utilizing a database shared by all the application programs (Jacobs et al., 2008). Along with providing enterprise-wide visibility, ERP systems enable standardization in reporting capability and data access.

ECSS is the supply chain ERP that will replace over 400 legacy systems, while still enabling product support and engineering, supply chain management, expeditionary logistics Command and Control, acquisition and procurement, and maintenance, repair, and overhaul (Dunn, 2007). Replacing the disparate legacy systems with one ERP enables asset visibility yielding on-time request. That is, implementation of ECSS will reduce transaction time between order and delivery providing logistics support to the Warfighter. Furthermore, the ERP will synchronize operational and logistics planning and execution enabling dynamic supply chain re-planning. Implementation of this ERP began in 2007 and is projected to be Fully Operational Capable (FOC) by 2013 with the last legacy system to sunset in 2020 (USDoD, 2007a).

Currently, DoD financial management is noncompliant with directives from the USAF, United States Transportation Command (USTC), Defense Finance and Accounting Service (DFAS), DoD, and Legislation (Gustafson, 2007). Furthermore, the financial management has multiple point-to-point interfaces, long processing times, and old technology, some of which is over 20 years old and requires systemic and manual workarounds (Gustafson, 2007). DEAMS, the Air Force financial ERP, is therefore being implemented to ensure the Warfighter has timely, accurate and reliable financial information. Implementation began in 2007 with projected FOC by 2010 and the sunset of the last legacy system the same year (USDoD, 2007a).

Both ECSS and DEAMS will each use a single instance Oracle® solution, which is a commercial-off-the-shelf (COTS) tool, along with industry best business practices (USDoD, 2007a). Interfaces between the two systems will facilitate tracking of department funds and assets. As seen in Figure 1, the current logistics architecture

requires multiple interactions with separate departments and data storage, whereas the future architecture depicted in Figure 2 will have fewer interactions because the necessary data will be centrally located within the ERP system. Every interaction between departments can take days to respond to a request. Thus, eliminating interactions will enable the Warfighter to get what they need sooner. Because the entire Air Force will be affected by the two ERP systems, the successful implementation of the systems is vital. A review of ERP implementation is presented in the following section.

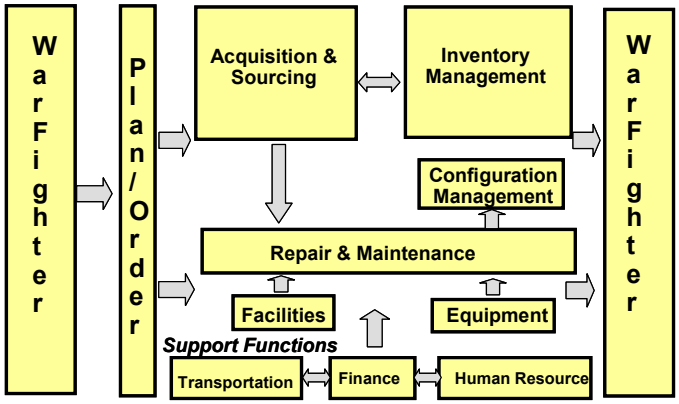


Figure 1 – Air Force As-Is Logistics Architecture (USDoD, 2005)

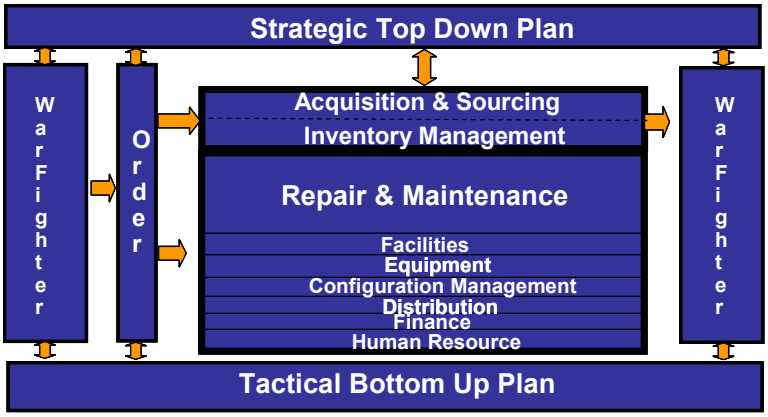


Figure 2 – Air Force To-Be Logistics Architecture (USDoD, 2005)

2.2 Problem Statement

The combination of new processes, software, and enterprise architecture is expected to increase individual network workload thus causing increased traffic at the SDPs, which are bottlenecks in the AF communications network (Fitzgerald & Harper, 2008). As mentioned in (Ishii, 2006) it may be too costly to supply sufficient bandwidth for peak traffic, therefore it is of interest how the increased workload will affect network performance and how additional SDP bandwidth capacity will affect network performance.

3 Literature Review

3.1 ERP Implementation

Today's ERP systems began as simple computer applications in the late 1960s, and evolved as hardware and software improved and the need for integrated enterprise functions became necessary for companies to survive in a competitive manufacturing environment (Jacobs & Weston, 2007). ERP systems have become popular because of the overwhelming financial and operational benefits resulting from successful implementation. These benefits include the reduction in data redundancy and errors across the enterprise, reduction in time to complete business processes, and increasing interaction between normally disconnected software applications and disparate departments (Bergdolt, 2007). Furthermore, facilitation of reengineering business processes, global operations, and competitive agility are some business benefits of ERPs, while the facilitation of more flexible and scalable architectures is a benefit from a technical perspective (Scott & Vessey, 2000).

The DoD and many industry case studies discuss the success and failure of ERP implementation within their respective organizations. The US Navy Air Systems Command obtained a cost savings between $10 million and $15 million per year by replacing 52 legacy systems with an ERP, which reduced the approval time for aircraft engineering change proposals from 87 days to 25 days (Bergdolt, 2007). Nestle USA was able to save $325 million with the implementation of an ERP in its supply chain

management (Bergdolt, 2007). Failed attempts at ERP implementation have resulted in a sales decrease of 12.4% and an earnings decrease of 18.6% at Hershey Inc. from 1999 to 2000, the cancellation of Dell's ERP system after 2 years because it could not support the required processes, and perhaps the most notorious ERP failure, the bankruptcy claim of FoxMeyer Drug Corporation (Scott & Vessey, 2000). From these case studies, and similar studies, recommendations and strategies have been proposed to stifle the long record of ERP failures. The remainder of this section reviews previous research in ERP implementation to explore potential applications of modeling and simulation for ensuring success of the Air Force ERPs.

From past implementation of smaller ERP systems, the DoD has learned that ERP systems require a comprehensive data structure, it is better to use the implementation strategies and tools provided by commercial-off-the-shelf (COTS) vendors, and it is necessary to re-engineer business processes to conform to industry best practices (Owens, 2007). Furthermore, from experience the Air Force has listed the top ten reasons ERP implementations fail as:

1) Governance

2) Scope

3) Change Management

4) Skills

5) Decision Making

6) Communications

7) Custom Development

8) Training

9) Culture; and

10) Leadership.

Overall, there is lack of ownership, dedication and buy-in, communication, and strategic methodology for ERP implementation (Owens, 2007).

Much industry research on ERP implementation has focused on Critical Success Factors (CSFs), which are defined by (Sherry & Corbett, 2007) as "those conditions that must be met in order for the implementation process to occur successfully." Most of the CSFs tend to be qualitative and business oriented, such as seen in Table 1. According to the sources listed in the table, if these factors are considered carefully then the ERP will succeed. Some CSFs are more analytical and technical. That is, better planning and analysis around these factors will increase the likelihood of successful ERP implementation. These factors include resource planning (Han, 2004) (Kim et al., 2005), IT infrastructure and hardware planning (Babey, 2006) (Ehie & Madsen, 2005) (Finney & Corbett, 2007), empower decision makers (Finney & Corbett, 2007), transition planning and data conversion (Berchet & Habchi, 2005) (Finney & Corbett, 2007), ERP system integration with other information systems (Berchet & Habchi, 2005), troubleshooting and crisis management (Finney & Corbett, 2007), and system testing (Finney & Corbett, 2007).

Table 1 – Qualitative CSFs

support from senior management	(Berchet & Habchi, 2005) (Bergdolt, 2007) (Ehie & Madsen, 2005) (Finney & Corbett, 2007)
reengineering business practices	(Berchet & Habchi, 2005) (Bergdolt, 2007) (Ehie & Madsen, 2005) (Finney & Corbett, 2007)
scope	(Al-Mashari & Al-Mudimigh, 2003)
ownership and transference of knowledge	(Al-Mashari & Al-Mudimigh, 2003) (Finney & Corbett, 2007)
change management	(Al-Mashari & Al-Mudimigh, 2003) (Finney & Corbett, 2007) (Kim et al., 2005)
communication	(Al-Mashari & Al-Mudimigh, 2003) (Finney & Corbett, 2007)
sufficient performance measurement	(Al-Mashari & Al-Mudimigh, 2003)
integration of IT and business affairs	(Al-Mashari & Al-Mudimigh, 2003) (Huang et al., 2004)
investment and user training	(Berchet & Habchi, 2005) (Finney & Corbett, 2007) (Huang et al., 2004)
standardization (lack of customization)	(Berchet & Habchi, 2005) (Huang et al., 2004)
careful selection of software and vendor	(Berchet & Habchi, 2005) (Finney & Corbett, 2007) (Kim et al., 2005)
cross-functional coordination	(Huang et al., 2004) (Kim et al., 2005)
employee morale	(Finney & Corbett, 2007) (Kim et al., 2005)
data conversion and integrity	(Bergdolt, 2007) (Finney & Corbett, 2007)

Implementing the AF ERPs will be challenging because over 400 legacy systems will be collapsed and the need for change management, reengineering business processes, and adopting industry best practices (Bergdolt, 2007). It was stated by (Han, 2004) that research on ERP implementation found that the expectations of ERPs will not be fully realized unless a holistic approach is taken in planning, acquiring, implementing, and exploiting. Thus, modeling and simulation should be utilized throughout Air Force ERP implementation to ensure the ERPs will operate as expected. More specifically, simulation could be used to analyze and ensure proper implementation of the analytical CSFs discussed above. By modeling the IT infrastructure, decision makers can base their resource decisions on statistical output from simulation runs rather than speculative predictions. Furthermore, simulation could be used to perform system testing and plan the

transition from legacy systems to ERP systems and integration with other information systems.

3.2 Modeling and Simulation for ERPs

Modeling and simulation for ERP systems commonly refers to the modeling of ERP requirements and architecture or the use of ERP data as input for a simulation. However, Nova Technology Solutions proposed the use of simulation to analyze the effects of ERP implementation on an existing IT network, leading to the focus of this paper, which is the use of simulation for IT infrastructure at the AF SDPs (Fitzgerald & Harper, 2008). The following subsections review the research in integration of ERP data with simulation, ERP architecture modeling, and simulation of IT infrastructure.

3.2.1 Integration of ERP Data with Simulation

Because ERP systems store mass amounts of data, it is an ideal source of input data for simulation models. An example where ERP data has been integrated with a simulation model is a printing company who used ERP data, such as inventory, demand, and due dates, in a simulation model to determine the required level of process detail in a printing process (Musselman, 2001). Another example is a health care facility that used a simulation model to evaluate different schedules produced by an ERP system. That is, discrete event simulation was used to determine the daily workload for different scheduling strategies in a cardiology department (Groothuis et al., 2002). Another case study describes a simulation model that used ERP data, such as setup times, process times, and routing data, to model a realistic lead time (Moon & Phatak, 2005). This lead time was used by the ERP system in planning shift schedules, preventative maintenance,

and labor capacity. The above case studies demonstrate the benefits of ERP data for simulation, but the application of ERP data as input is only valid once the ERP has been successfully implemented. As the Air Force ERPs are not fully operational, it is desired to use modeling and simulation in the planning and implementation of ERPs (Fitzgerald & Harper, 2008).

3.2.2 ERP Architecture Modeling

For all Air Force missions and initiatives extensive architecture modeling is done to ensure compliance, effective decision making, and organizational change. Architecture is defined as the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time (USDoD, 2007b). The Department of Defense Architecture Framework (DoDAF) is composed of three primary views. The Operational View (OV) captures the processes, data types, and data flow necessary to accomplish DoD missions, while the Systems/Services View (SV) models the systems and interconnection functionality between systems that support the operational activities and the Technical Standards View (TV) defines the rules governing the arrangement, interaction, and interdependence of system parts or elements (USDoD, 2007b).

Similar modeling methodologies are implemented in industry, such as the Architecture of Integrated Information Systems (ARIS) and Dynamic Enterprise Modeling (DEM) (Soffer, 2003). The ARIS method is comprised of five views. The functional view provides a hierarchy of activities, the business process view lays out the work flows with event-driven process chains, the resource view depicts which organizational units and other resources perform the operational activities, the data view

defines the types of data used in all the systems, and the output view defines the physical inputs and outputs of the system (Soffer et al., 2003). The DEM modeling methodology contains a business control view, which represents business functions and their structure and interactions, an organizational structure view, an enterprise structure view, and a business process view.

As depicted in (Fitzgerald & Harper, 2008), modeling methodologies provide the basic information and structure necessary for simulation models. Such simulations can be used to gain insight to the dynamics and uncertainty of systems, which can aid in architecture decision-making. For the Air Force ERP implementation problem, OV and SV information could be translated into a simulation model to determine the optimal IT infrastructure.

3.2.3 Simulation of IT Infrastructure

IT infrastructure is a set of shared IT resources, such as hardware, software, networks, and applications, which is a foundation for both communication across the organization and the implementation of present/future business applications (Chanopas et al., 2006). The following literature review covers case studies that implemented simulation of IT infrastructure. In particular, simulation of computer networks and hardware components are reviewed.

A queue simulation was used to analyze the bandwidth performance of a router in (Ishii, 2006). Bandwidth requirement is the minimum bandwidth needed between two nodes to satisfy a quality standard, or allowable quality deterioration. Quality deterioration is packet queuing delay and packet loss that occurs when traffic along a link is greater than the bandwidth. Because it might be too costly to supply sufficient

bandwidth for peak traffic, a simulation was used to determine the bandwidth that will reduce the maximum queuing delay to within the reference value, and determine the bandwidth needed to reduce the x% value of the queuing delay to within the reference value. The simulation tool was comprised of a packet monitor, queue simulator, and bandwidth requirement estimator. The packet monitor captures packet size and arrival time of each packet from a real Ethernet and sends the information to the queue simulator. With the packet data, the queue simulator placed virtual packets into a queue from which the queuing delay and packet loss rate of each packet are estimated. The estimations are used by the bandwidth requirement estimator to calculate the bandwidth requirement, which is then used by the queue simulator to modify the queue service rate. Experimentation with video traffic showed that the designed simulation tool was generally inadequate for estimating bandwidth requirement for highly bursty traffic.

A simplified Ethernet algorithm was implemented in (Fukuda, 2000) to simulate packet flow between two nodes. The purpose of the paper was to analyze the competition between nodes sending packets along a shared media, and analyze the exponential back-off algorithm in collision detection. The inputs for the discrete simulation algorithm are rate of packet creation for each node, maximum output queue size, and the back-off counter limit. Packet creation, or arrival, rates were generated from real data captured from a university Ethernet network. From packet sizes and frequency of arrival it was found that there are two basic periods of congestion and transmission of packets. Sparse periods have a mean flow density of 150 Kbytes/s, while congested periods have 850 Kbytes/s. In the simulation algorithm packets are generated and placed in the node queue until it can be transmitted to the next node. At fixed intervals each node attempts to send

a packet, but if there will be a collision then the back-off counter sets a wait time until the node attempts to resend the packet. If a packet arrives at a node and there is no room in the queue, then the packet is simply dropped. The output data from the algorithm includes packet dropping rate, which is the number of packets overflowing at either node over the total number of input packets. During experimentation different variations of packet transmission rate, arrival rate, queue length, and back-off maximums are tested to gain insight to how the Ethernet network behaves. When outputs from the algorithm were compared to real Ethernet data, it was found that the algorithm successfully simulates the traffic behaviors of the real system. That is, a low traffic flow rate results in few packet collisions.

Behavior of file servers, or web servers, is simulated in (Field, 2004) for network traffic in a university department. A modified single server simulation was used to model a file server that removes blocks of work from the queue to simulate Ethernet frames, and then waits after each frame to simulate the inter-frame gap. Packets arrive at the server in clusters, like transactions, but packets leaving the server are separate and are emitted according to the network speed. From experimentation it was found that the simulation produces the correct distribution of both web server and file server response sizes, in terms of the number of Ethernet packets required to transmit them.

A network simulation was developed at University of Louisville as a teaching aid for computer science classes (McCoy, 1981). The model simulates traffic between devices, and between devices and processors, with user think-times as inter-arrival time for transactions and computer response time as service times. Along with identifying bottlenecks, the simulation was used to determine the maximum number of terminating

devices and processors that the terminal interface processor can handle given various hardware and software response times, and to determine what queue sizes should be implemented to efficiently handle I/O requests.

The above case studies discuss problems that are similar to the USAF network problem in that they simulate packet flow and network components to evaluate network performance, but they do not have the complexity and large scope of the USAF problem. The USAF network is extremely complex and spans the entire nation; it is of interest if the network can even be modeled with enough validity to get meaningful results. Some insight to this problem can be obtained from research presented in (Floyd, 2001), which discusses the difficulties of internet simulation. Two primary issues in simulating the internet's complexity are network heterogeneity and rapid change. Although rapid change may not be as prevalent in the USAF network as in the global internet, the issue must be considered. Heterogeneity refers to the variation and differences in protocols, applications used at sites, levels of congestion seen on different links, topology and link properties, as well as many other factors. Protocols can differ when different communities implement protocols, often with different features and bugs. Traffic generation is complicated for large networks because there are many traffic sources entering the networks from different locations and with different packet characteristics. Dynamic routing and different types of links, such as slow modems versus fiber optics, form further model complexity. The two strategies discussed for developing valid simulations are searching for invariants, and judiciously exploring the simulation parameter space. As stated in (Floyd, 2001) "an invariant is some facet of behavior which has been empirically shown to hold in a very wide range of environments." Invariants

helpful in simulating the internet include self-similarity, Poisson session arrivals, Log-normal connection sizes, and heavy-tailed distributions. By exploring a parameter space it can be determined how sensitive the simulation output is to changes in the input parameters, thus enabling parameter relaxation, which is the allowance of a range of values for a parameter, to cope with network change and heterogeneity (Floyd, 2001).

4 Model Development

4.1 Discrete Event Simulation

To analyze SDP capacity, a discrete event simulation was used to simulate network traffic (Fitzgerald & Harper, 2008). Discrete event simulation passes entities between blocks based on events that mimic real-world activities. Instead of advancing continuously, the simulation clock advances according to the next scheduled event (Kelton et al., 2004). The steps for completing a simulation project are as follows:

1) Understand the system
2) Be clear about your goals
3) Formulate the model representation
4) Translate into modeling software
5) Verification of the model
6) Validation of the model
7) Design the experiments
8) Run the experiments
9) Analyze the results
10) Get insight; and
11) Document what you've done (Kelton et al., 2004)

This simulation methodology was used in completing the NovaTech project and the thesis project outlined below.

4.2 ExtendSim® Software

The discrete event simulation model was built with ExtendSim® software version 7, which is a process-oriented simulation tool by Imagine That Incorporated. Used throughout DoD, ExtendSim® has also been utilized by industry leaders such as NASA, Caterpillar Inc., Boeing, and IBM Global Services (Imagine, 2008a). Although only used for discrete event simulation for this project, ExtendSim® is a multi-domain environment capable of modeling continuous, discrete rate, agent-based, linear, non-linear, and mixed-mode systems as well. This powerful, leading edge simulation tool implements an easy-to-use graphical interface consisting of unlimited hierarchical decomposition and a set of building blocks that enables rapid production of process simulations (Imagine, 2008b). Rapid and in depth data analysis is enabled by ExtendSim's customizable reports and plotters, the capability to pass values, arrays, and structures composed of arrays, and full connectivity and interactivity with other programs and platforms (Imagine, 2008b).

4.3 The Model

4.3.1 Overview

The basic concept of the model is the flow of data packets across the Air Force IT infrastructure, or communications network. Like the simulation discussed above for (McCoy, 1981) transactions are generated by an end-user which travel between devices, and between devices and processors. In the AF model, an end-user located at Base X generates a transaction, e.g. a DEAMS user wants to generate a finance report, which must be processed at an application server located at Base Y, refer to Figure 3. The transaction splits into packets that travel across the LAN and SDP at Base X, the WAN,

and the SDP and LAN at Base Y. After the packets have been processed by the application server they travel back through the network to the end-user. A single transaction is considered complete when the last packet returns to the end-user's computer. Refer to Figure 4 for a top level view of the model in ExtendSim®.

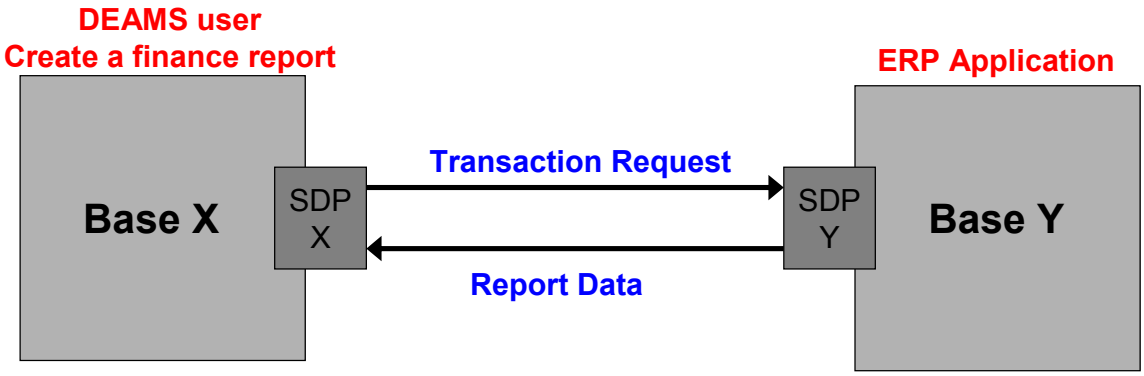


Figure 3 – Conceptual Model

As any discrete event simulation the AF IT model consists of entities, resources, and activities. Like the simulations discussed in section 3.2.3, the entities flowing through the model represent packets, either end-user transaction packets or filler traffic packets. Filler traffic packets are created to simulate traffic generated by other AF users on the network, and these packets are discarded once they flow through the SDP. There are four create blocks that generate filler traffic packets, which correspond to Base X inbound traffic, Base X outbound traffic, Base Y inbound traffic, and Base Y outbound traffic. End-user packets are generated to track and collect the response time for a single end-user transaction. That is, end-user packets are not meant to add contention to the SDP queue, but simply create a trigger for a transaction arrival and completion. Each SDP is modeled as a parallel combination of 2 single server single queue systems, where one resource strictly processes inbound traffic while the other strictly processes outbound traffic. Thus there are four resources in the model: Base X SDP Incoming; Base X SDP

Outgoing; Base Y SDP Incoming; and Base Y SDP Outgoing. Because the IT infrastructure at each base is unique and could change frequently, the model detail was maintained at a basic level in which the activities in the model represent the delay encountered by part of the AF IT infrastructure. These activities include LANs, SDPs, the WAN, and an application server.

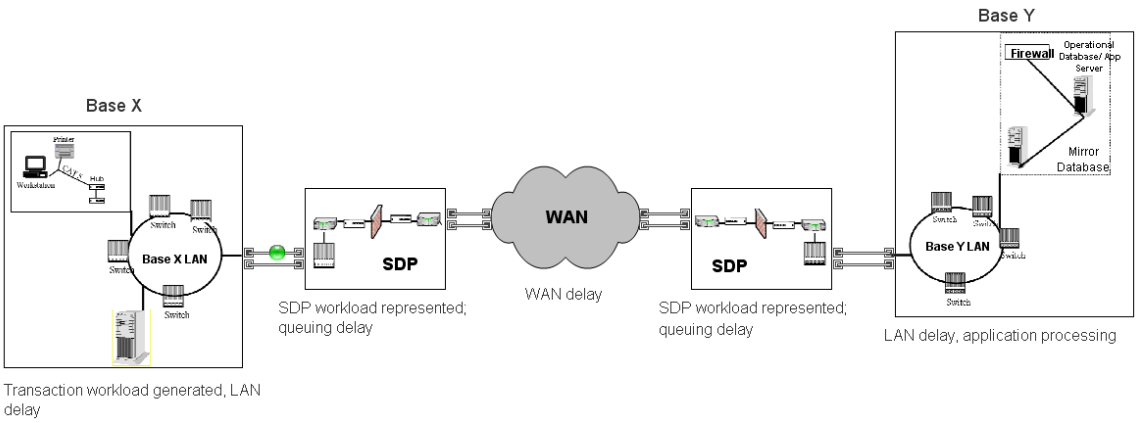


Figure 4 – Top Hierarchical View of Model (Fitzgerald & Harper, 2008)

4.3.2 Assumptions

Due to restrictions for available data and time, assumptions were made about the model, the input data, and the real system.

Individual network components were not modeled because each SDP has a unique architecture and that specific data was unavailable. Therefore, unlike the study done by (Ishii, 2006), the model does not go to the level of detail of routers, switches, firewalls, etc., but rather models them as a combined delay for the LAN, WAN, and SDP. Furthermore, unlike the studies done by (Fukuda, 2006) and (McCoy, 1981) network characteristics such as CPU, I/O, internet protocols, and links between hardware (i.e. fiber optics, coax, etc.) were not simulated because these network characteristics were beyond project scope along with packet loss and packet retry. Packet loss occurs when

there is insufficient space in a hardware buffer for a packet, which triggers a message to resend the packet. Because packet retry can potentially overload a system it was considered beyond project scope, therefore it was assumed that queues could have unlimited length.

Data packets usually range from around 500 Bytes to a maximum of 1500 Bytes (Microsoft, 2007), so it was assumed that all packets in the model are 1 KB in size. Leading IT companies such as Lexis Nexis use 5 seconds as web response time standard (Fitzgerald, 2008), while some research determined that user perceived response tolerance is around 8 to 10 seconds (Bouch et al., 2000). For the model, the standard response time was assumed to be between 5 and 10 seconds. As discussed above, the simulation of a file server by (Field, 2004) included logic to account for packet gap, but the model built for the AF problem combined packet gap and other overhead requirements into the SDP bandwidth capacity. That is, to account for overhead requirements, such as packet gap, packet structure and preamble, 20% of SDP bandwidth capacity was modeled as unavailable to entities. In the model this was done by calculating the SDP process time according to Equation 1. After the end-users transaction has been processed by the application server the returning report is assumed to be larger than the incoming request. For this reason it was assumed that the number of packets returning from the application server would be double the number sent by the user. An unbatch block was used in the Extend model to duplicate the entities, resulting in twice the number of packets returning to the end-user.

$$\text{SDP Process Time} = \frac{1}{0.8 * Capacity}$$

Equation 1

4.3.3 Input Data

Because the NovaTech project and extended work of the thesis were not completed under a government contract, access to real data was limited. Therefore, model data is based mainly on NovaTech and DSD Laboratories internal SMEs' knowledge and typical IT observations. The input data needed for the model consists of delays for the LANs, WAN, and application server, SDP bandwidth capacity, end-user transaction size, and filler traffic throughput for the SDPs.

As done for the simulation in (McCoy, 1981) computer response times were used as service times, but due to the lack of actual data a Precise distribution could not be fitted to actual data. For this reason uniform distributions were used for the LAN, WAN, and application server service times. Through SME interviews the service times for these delays were set as provided in Table 2.

Table 2 – Input Data for Model Delays

Model Delay	Distribution	Units
WAN	Uniform(40, 120)	sec / 100 packets
LAN	Uniform(30, 60)	sec / 100 packets
Application Server	Uniform(100, 150)	sec / 100 packets
SDP Base X	Constant(0.0167)	sec / 100 packets
SDP Base Y	Constant(0.0185)	sec / 100 packets

It is assumed a typical transaction for a DEAMS user is approximately 300 KB in size with time between transactions in units of minutes or hours. Because the traffic from a single end-user is typically small relative to the total traffic on the network it does not by itself affect queuing extensively. Changes in end-user transaction size will increase the response time with a trend because the packets will encounter the same queuing delays but the time for more packets to be processed and returned will be larger. In the experiments the return of end-user transaction packets served as triggers to signal when a

transaction is complete and caused output statistics to be collected in the model. Transactions were created with a time between transactions that was exponential with a mean of 10 seconds.

As stated before, each SDP is configured for a maximum of 100 MBps, but is leased according to requirements and affordability, thus Base Y currently has 54 Mbps while Base X has 60 Mbps. Because packets are measured in KB these capacity values were converted to KBps, then reduced by 20% for overhead requirements (packet gap, packet preamble, etc.), and finally translated into process times for the SDP input data. (Fitzgerald & Harper, 2008)

Filler traffic inter-arrival rates were determined by a process similar to the packet creation rates in (Fukuda, 2000), but as the real data was unavailable notional IT throughput data typical of IT traffic was substituted. Typical IT traffic is characterized by peaks during the morning and afternoon hours and peak daily traffic on Tuesdays (Fitzgerald, 2008). Data representative of typical end-user sites is represented in Figure 5 and Figure 6. To extract the data values from string format, an Excel VBA macro was coded and used (refer to Appendix G). Because the data points were averages over 5 minute periods and were not independent because bits are sent out in batches, the variance and precise distribution of the data could not be obtained. Therefore, exponential distributions were implemented for inter-arrival times and varying loads throughout the day were obtained by averaging consecutive points with similar throughput values, leading to smoothed stepped averages as seen by the red lines in Figure 7. Using the formula below these stepped averages were converted into inter-arrival times for the filler

traffic that were used as input to the model. Refer to Appendix D for the filler traffic inter-arrival times.

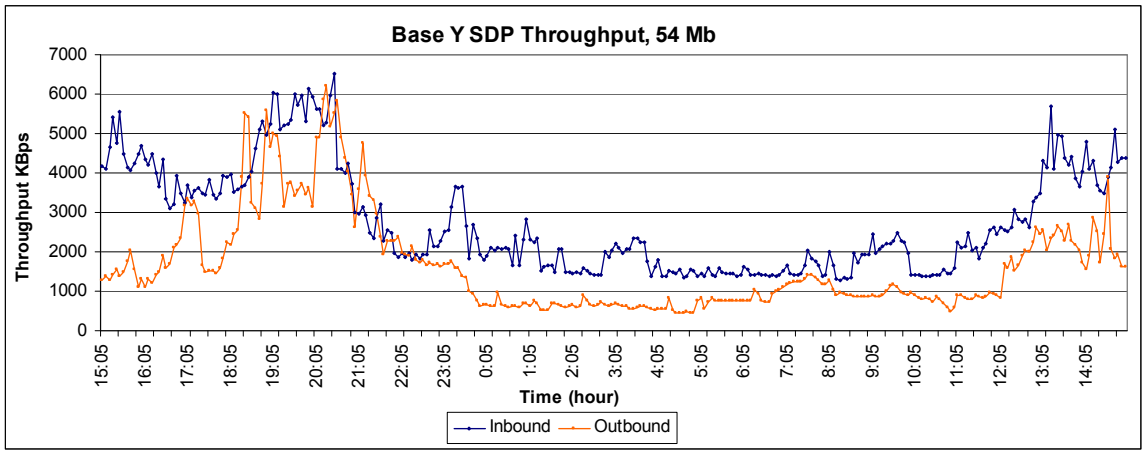


Figure 5 – Base Y SDP Original Data (NovaTech work source)

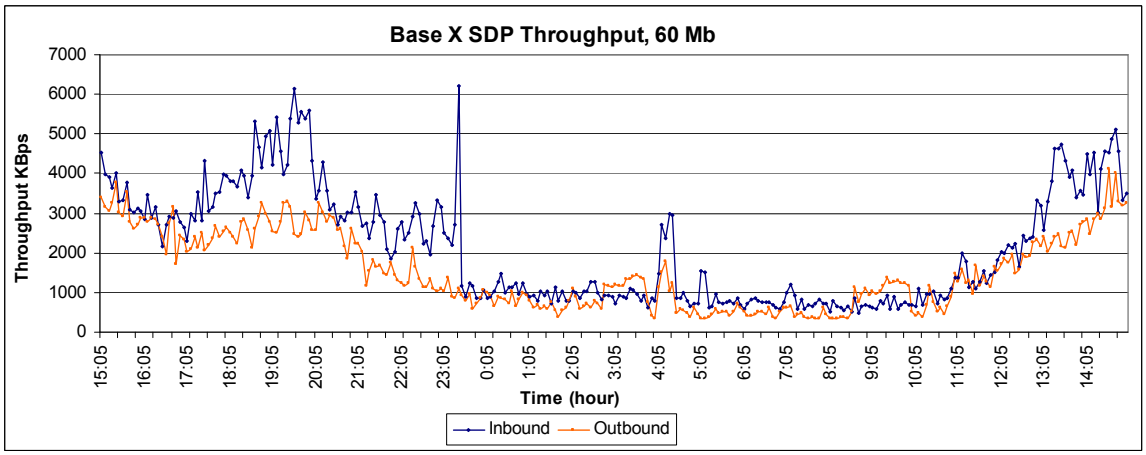


Figure 6 – Base X SDP Original Data (NovaTech work source)

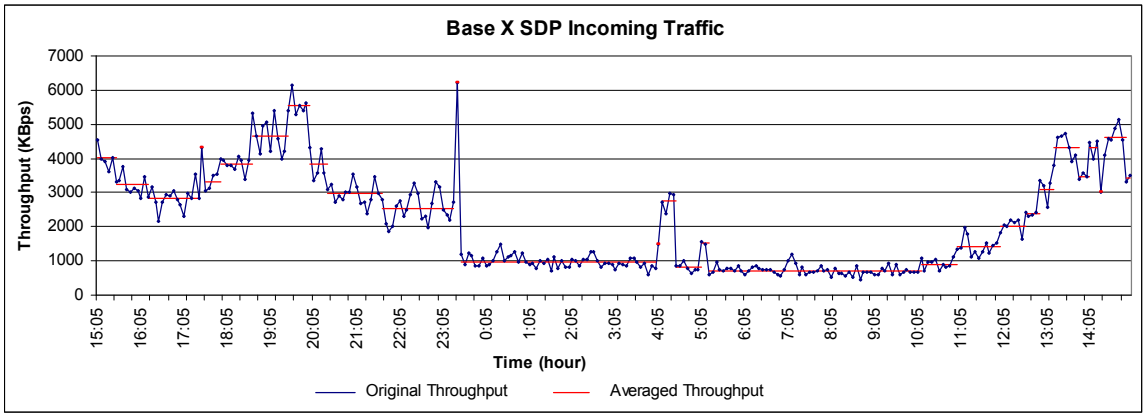


Figure 7 – Base X Averaged Incoming SDP Data

In order to start a simulation model in a "representative" state, it is good practice to run the simulation through a "warm up" period. To warm-up the model, filler traffic data from 5:00 to 15:00, where there is consistently low traffic, was duplicated and added in front of the 15:05-15:00 data. This resulted in a simulation run length of approximately 34 hours. After running a few initial test runs, it became apparent that runtime for the simulation with each entity representing a 1 KB packet would extend over 24 hours real time. This was a result of the extremely large number of entities that must be processed by the model in this case. Therefore, the model was changed to enable each entity to represent 100 packets. By doing this all delays, inter-arrival times, and the end-user transaction sizes were changed accordingly, as seen in Table 2. The resulting runtime ranged between 30 and 50 minutes, which was acceptable.

4.3.4 Output Data

The performance measures, or output data, from the simulation model are end-user response time and Base Y SDP utilization. Response time is the time from transaction creation to the time the last packet returns to the end-user, therefore this performance measure was collected when a transaction was completed. Base Y SDP utilization data

was collected within an ExtendSim® "statistics" block that used the batch means statistical method to collect observations every 5 minutes of simulation time. Observations were chosen to be collected every 5 minutes because this is the smallest increment of time between changes in the filler traffic input data. At the end of the simulation runs the data collected during the simulation was exported to an Excel spreadsheet.

Exporting the output data to Excel facilitated the use of Excel VBA macros for rapid data formatting and analysis. Five macros were coded to automate the functions of clearing data from the worksheets, formatting response times and utilization data, and calculating hourly and five-minute averages. Refer to Appendix G for the VBA code.

4.3.5 Verification

Verifying that the ExtendSim® model was running as expected was done by observing model animation and collecting data from various deterministic runs and stochastic runs. Running a deterministic model verified that entities were being routed correctly and that the calculated response time was as expected. Data collected during stochastic simulation runs, via plotter blocks, was analyzed within the JMP statistical software to verify that the create blocks and activity blocks were providing valid distribution output. Of particular interest was ensuring the changes in inter-arrival rates according to a lookup table were being properly implemented in the model. Another step in verifying the model was comparing the theoretical SDP utilization, which is the filler traffic throughput (KBps) divided by the SDP capacity (KBps), to the actual utilization output from the model. As seen in Figure 8 and Appendix E, the utilization from the simulation closely follows the

theoretical utilization except when the theoretical utilization exceeds 100%. From this plot it was verified that the simulation was producing filler traffic as expected.

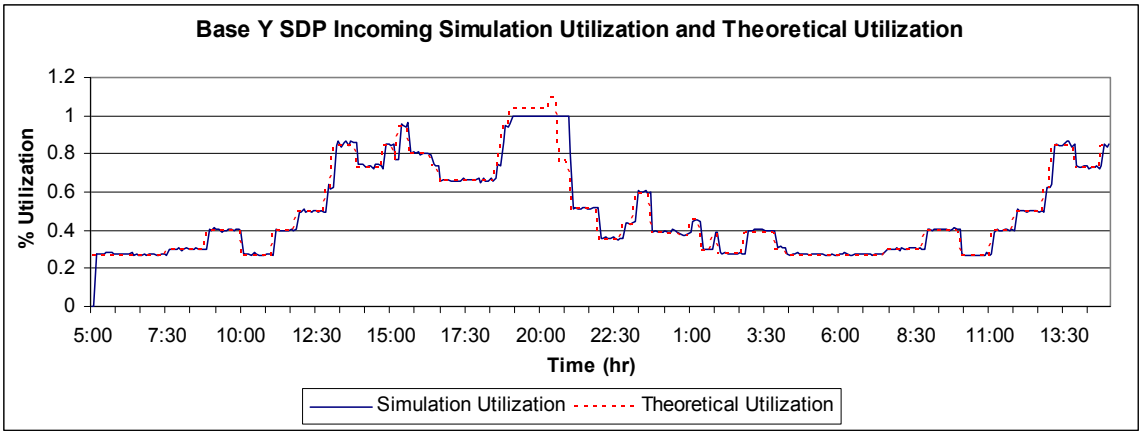


Figure 8 – Example Theoretical Utilization and Simulation Output Utilization Plot

4.3.6 Validation

The validation procedure relied mainly on NovaTech SME knowledge of the real system and general IT standards. Stepping through the model logic with these internal SMEs with expertise in simulation, IT, and AF SDP architecture led to what is believed to be a valid model. Furthermore, reviewing and comparing simulation output to SME expectations and industry standards confirmed that the model is representative of the AF IT network system. Thus, the model is claimed sufficient for use in analyzing the AF ERP challenge.

5 Analysis

Using response time as the performance measure, statistical experiments were run to analyze the impact of increased workload and the effect of increased SDP bandwidth capacity. The statistical experiment for increased workload was designed with four levels of filler traffic to simulate increase network traffic due to larger transactions from ERP use, refer to Table 3. Five simulation replications were run for each of the four levels, which were current workload and 10%, 20%, and 30% workload increase from the current throughput (refer to Appendix D for filler traffic inter-arrival times). Similar workload increase experimentation was done with the NovaTech model, specifically a 15% increased workload (Fitzgerald & Harper, 2008).

Table 3 – Experiment 1 Design

Filler Traffic	Base X bandwidth (Mbps)	Base Y bandwidth (Mbps)
current workload	60	54
10% increase	60	54
20% increase	60	54
30% increase	60	54

To analyze the effect of adding bandwidth to the SDPs, an experiment was designed with the current SDP capacity level and an increased capacity level that would cover the maximum SDP throughput of the 30% workload increase filler rates. That is, the capacity was set at a level that would ensure theoretical utilization would never

exceed 100%, refer to Table 4. As in the first experiment, five replications were run for each of the two levels.

Table 4 – Experiment 2 Design

Filler Traffic	Base X bandwidth (Mbps)	Base Y bandwidth (Mbps)
30% increase	60	54
30% increase	60	76.93

For a single simulation run at each workload level, the output response times were plotted over time, see Appendix F. These plots show a pattern of about five seconds response time until the peak traffic hours. At these peak times noticeable queuing begins to occur around 95% SDP utilization.

For each workload level, hourly and five minute average response times were calculated, along with variance, standard deviation, and coefficient of variance. From the plots of the calculation results, refer to Figure 11, Figure 12, Appendix H, and Appendix I, it can be seen that variation increases as average response time increases and the five minute averages have larger variation than the hourly averages.

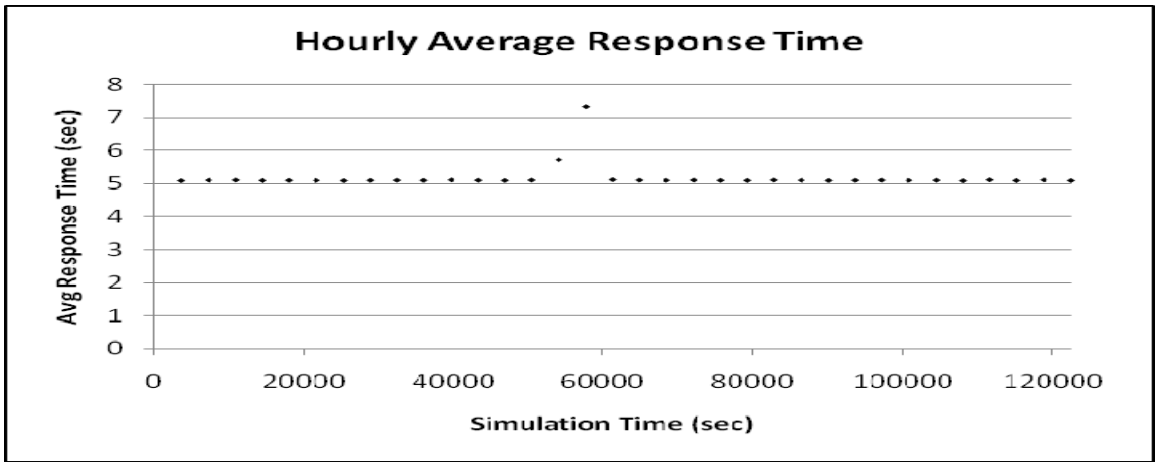


Figure 9 – Current Workload 1 Hour Average Response Times

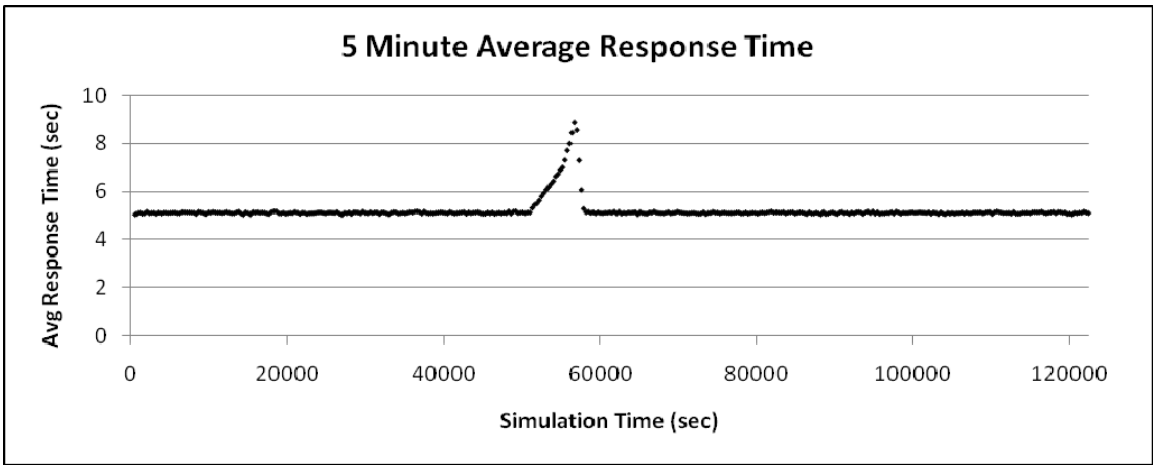


Figure 10 – Current Workload Five Minute Average Response Times

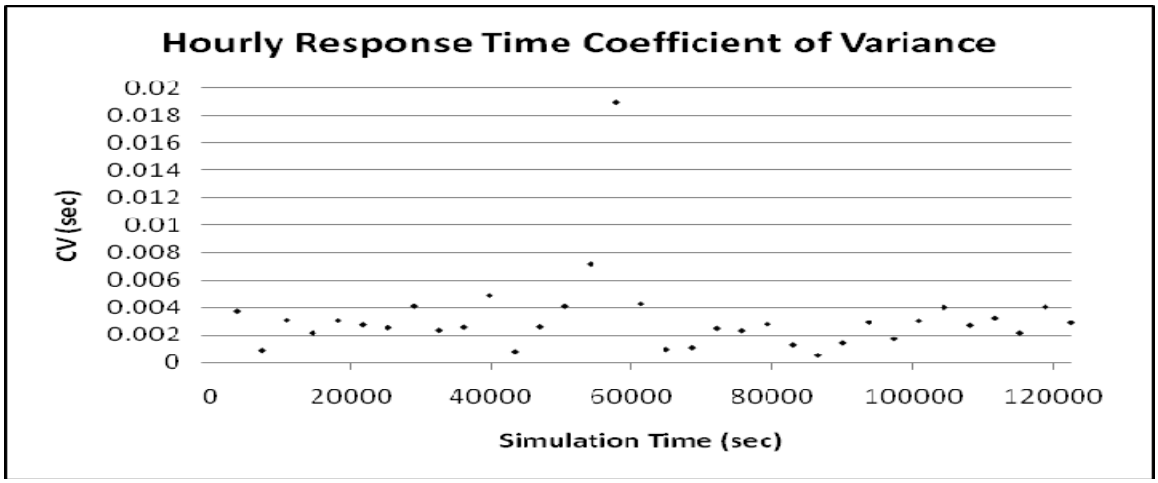


Figure 11 – Current Workload 1 Hour Response Time Coefficient of Variance

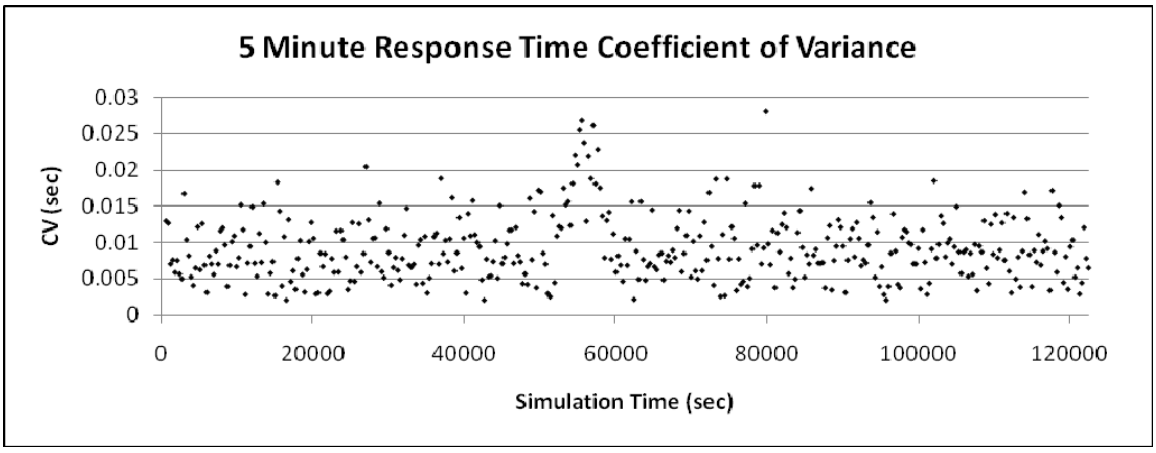


Figure 12 – Current Workload Five Minute Response Time Coefficient of Variance

By plotting end-user response times during peak hours against SDP utilization for each workload level (refer to Figure 13 and Appendix J) an exponential trend line was fitted to each plot resulting in equations to predict the response time given an SDP utilization value. Notice that response time increases as SDP utilization increases. Also, the response time variability increases and response time becomes less predictable as the SDP utilization increases. Using the fitted curve, for a given workload increase, or traffic increase, the end-user response time during peak hours can be estimated using the equation. Decision makers can use these response time estimates to determine if additional SDP bandwidth is required.

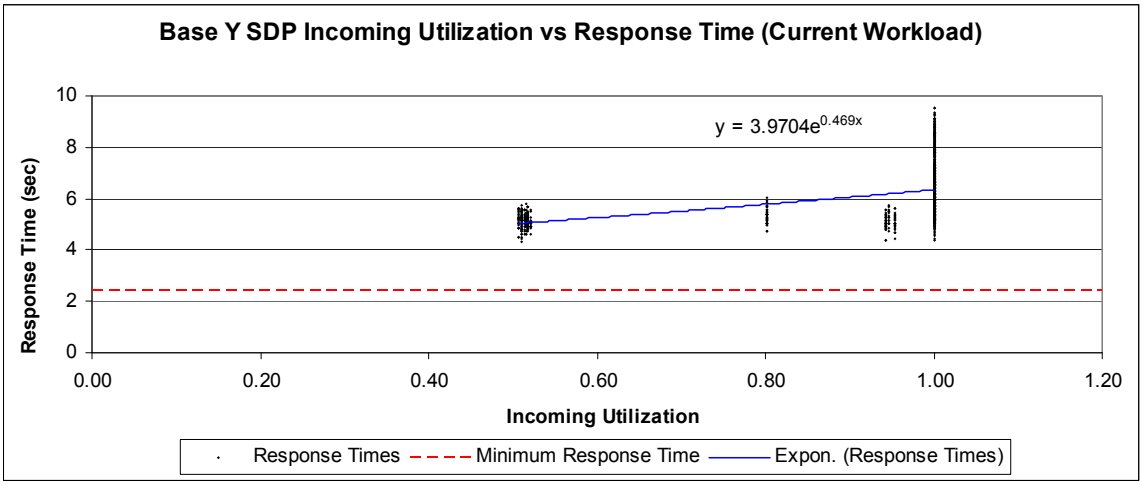


Figure 13 – Example Response Time vs. SDP Utilization Plot

The total day averages with 95% and 99% confidence intervals are provided in Table 5. As the confidence intervals do not overlap, the response time for each level of traffic is deemed significantly different than the other response times and the 30% increased traffic level has the largest average response time. Similarly, average response times were calculated for the peak 3 hours, and the peak single hour. From the confidence intervals for these averages, Table 6 and Table 7, it was determined that the average

response times are significantly different from each other and the 30% increased traffic level has the largest average peak 3 hours and peak single hour response time. Relative to the average response time for current workload, a 10%, 20%, and 30% increases in workload resulted in a 51.82%, 121.52%, and 191.43% increase in average response time during peak 3 hours, and a 98.05%, 208.91%, and 352.07% increase in average response time during the peak single hour, respectively. Furthermore, the tables show that the peak single hour has a larger average response time than the peak 3 hours and the total day. The maximum response time any single end-user experienced in each run is provided in Table 8.

Table 5 – Total Day Average Response Times for Workload Experiment

Traffic Level	Average (sec)	± 95% CI (sec)	± 99% CI (sec)
current Workload	5.1814	± 0.0036	± 0.0059
10% Increase	5.4981	± 0.0074	± 0.0123
20% Increase	6.0950	± 0.0266	± 0.0442
30% Increase	7.4090	± 0.0821	± 0.1362

Table 6 – Peak 3 Hours Average Response Times for Workload Experiment

Traffic Level	Average	± 95% CI	± 99% CI
current Workload	6.5782	± 0.0998	± 0.1656
10% Increase	9.9871	± 0.1348	± 0.2238
20% Increase	14.5718	± 0.1619	± 0.2687
30% Increase	19.1691	± 0.3468	± 0.5754

Table 7 – Peak 1 Hour Average Response Times for Workload Experiment

Traffic Level	Average (sec)	± 95% CI (sec)	± 99% CI (sec)
current Workload	6.9881	± 0.0869	± 0.1443
10% Increase	13.8401	± 0.1421	± 0.2358
20% Increase	21.5868	± 0.1481	± 0.2457
30% Increase	31.5909	± 0.2403	± 0.3988

Table 8 – Maximum Response Times (sec) for Workload Experiment

Traffic Level	Run 1	Run 2	Run 3	Run 4	Run 5	Average
Current Workload	9.5477	9.1573	9.6361	9.6058	9.1965	9.4287
10% Increase	16.4018	17.1890	16.7804	16.9989	16.9118	16.8564
20% Increase	24.8134	25.0394	25.0119	24.9728	24.8727	24.9420
30% Increase	34.6001	34.5666	34.4841	34.4829	34.8535	34.5975

For the SDP hosting the application server the percent of time, out of the 34 hour simulation run, the utilization was at or above 100% was calculated, refer to Table 9. From these calculations it was determined that the percent of time at or above 100% for theoretical utilization of the Inbound SDP resource increased by 2.3% from current workload level to 30% increased workload level, while the simulation results show a 4.3% increase in utilization. Similarly, for the Outbound SDP resource the percent of time at or above 100% utilization for theoretical utilization only increased by 1.6% from current workload level to 30% increased workload level, while the simulation results showed a 3.4% increase, respectively.

Table 9 – SDP Utilization Results

	% of Time SDP at or Above 100% Utilization			
	Inbound		Outbound	
	Theoretical	Simulation	Theoretical	Simulation
Current Workload	4.66	5.64	1.72	1.96
10% Increase	6.37	8.82	2.70	3.68
20% Increase	12.99	18.38	3.43	6.13
30% Increase	15.20	30.15	4.41	8.58

Depending on AF standards for response times, the resulting response times may be unacceptable requiring additional bandwidth capacity at the SDPs. In a second statistical experiment, the filler traffic was kept at the 30% increased workload level and two scenarios were run to determine how adding bandwidth capacity to a SDP affects response time. The first scenario was run with the current Base Y SDP capacity of 54 Mbps, while the second scenario was run with 76.93 Mbps, which is the level of capacity

needed to keep the theoretical utilization from exceeding 100%. From results of the second experiment, as seen in Table 10 and Table 11, it was determined that with the 30% increased workload level and the 42.47% increase in Base Y SDP capacity resulted in a 75.30% decrease in average end-user response time during the peak single hour and a 70.97% decrease in average maximum response time.

Table 10 – Peak 1 Hour Average Response Times for Capacity Experiment

Base Y SDP Bandwidth Capacity	Average (sec)	± 95% CI (sec)	± 99% CI (sec)
54 Mbps	31.5909	± 0.2403	± 0.3988
76.93 Mbps	7.8036	± 0.0790	± 0.1310

Table 11 – Maximum Response Time (sec) for Capacity Experiment

Base Y SDP Bandwidth Capacity	Run 1	Run 2	Run 3	Run 4	Run 5	Average
54 Mbps	34.6001	34.5666	34.4841	34.4829	34.8535	34.5975
76.93 Mbps	9.8723	9.9857	10.1438	10.0831	10.1316	10.0433

6 Discussion and Further Study

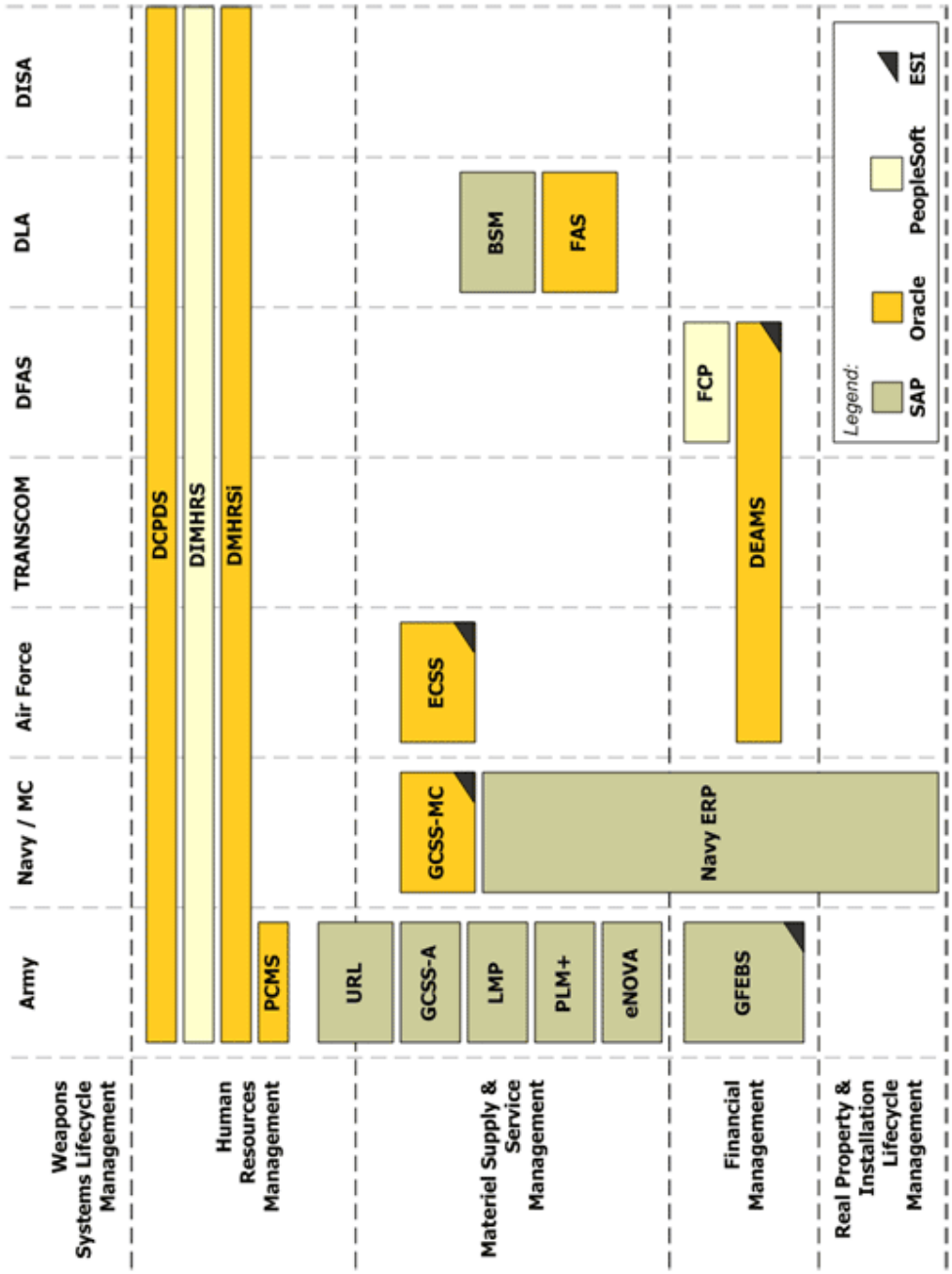
Through the work done with Nova Technology Solutions, a discrete event model was built in ExtendSim® to simulate packet traffic on a generic network representative of the USAF computer network. The model provides a tool for resource planning and IT infrastructure and hardware planning, proposed by NovaTech to augment decision making during the DoD Enterprise Transition Plan effort. This was demonstrated by the use of the network model to estimate the impact of ERP implementation on SDP capacity and end-users. Experimental results led to the conclusion that predicted workload increases of 10%, 20%, and 30% would significantly increase the end-user response time. With a 30% increase in workload the average response time was estimated to be 31.6 ± 0.4 seconds, at 99% confidence, during the peak hour of traffic. Further experimentation resulted in the determination that adding 42.5% more bandwidth capacity to the SDP of the base hosting the application server would decrease average response time by 75%.

With the current model, further experiments could be run to determine how increased workload affects the response time for various types of end-user transactions. Scenarios for such a study could include batch transactions that are large in size and infrequent, or small frequent transactions. Also, more experiments could be run to determine how adding different levels of bandwidth capacity affect response time at different levels of increased network traffic. The results from these experiments and the original experiments can be used to generate a response surface with bandwidth capacity,

response time and workload axis. This response surface provides a means for determining what SDP bandwidth capacity is needed to achieve a desired response time at a certain workload level. Cost of end-user work can be used to determine how an increase in response time affects overall AF cost. As response time increases, the end-user executes fewer transactions per day resulting in greater cost of operating. Other excursions could be run to analyze the recovery time during excessive queuing. That is, determine how long it takes for queuing to decrease to a certain point after the peak queue length is reached.

Enhancement to the model could be done by simulating packet loss and packet retry, which will magnify the response time by flooding the network with extraneous retry requests (Fitzgerald & Harper, 2008). This additional model logic and more detail can enable analysis of IT architecture specifics, such as server sizing, application efficiency, virtual load testing, ERP module management, configuration management, and data retrieval and reporting strategies.

Appendix A: DoD ERP Systems

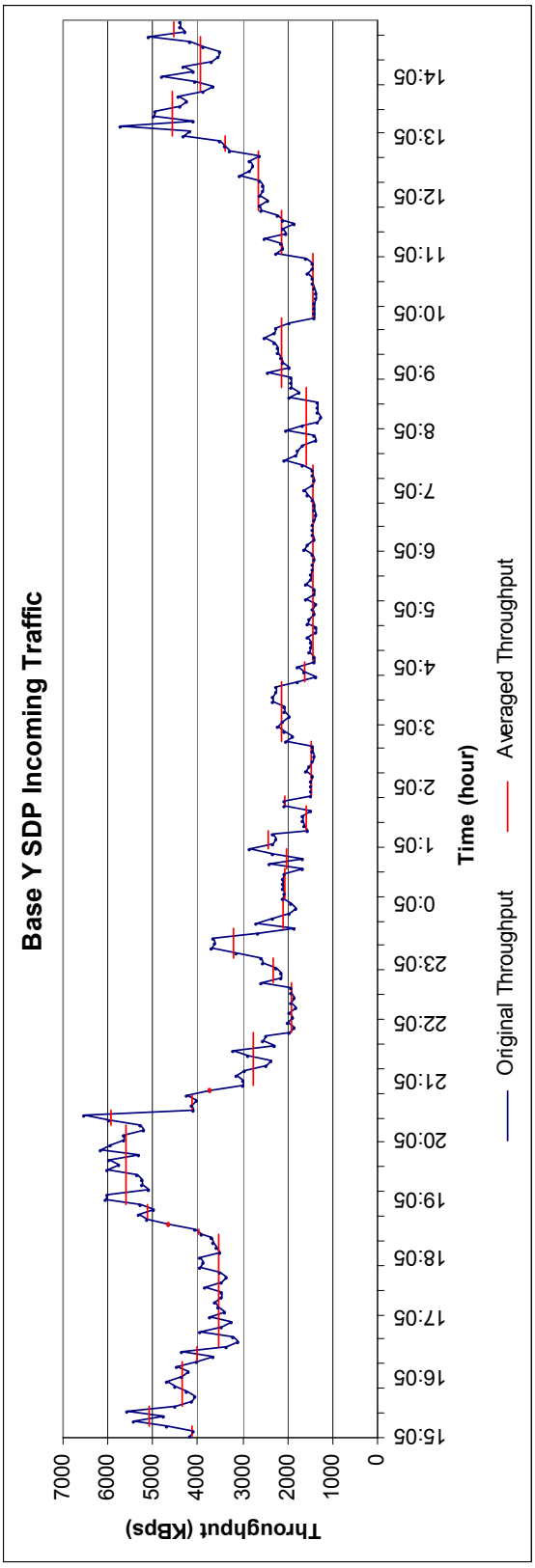


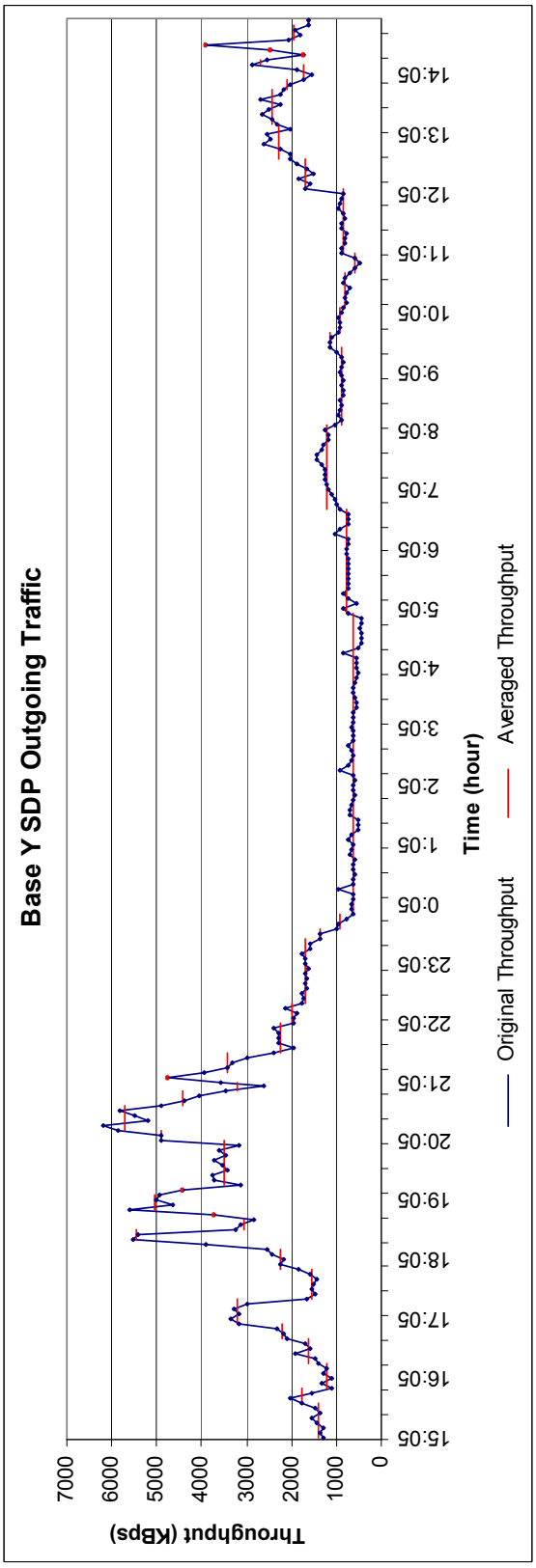
(USDoD, 2007a)

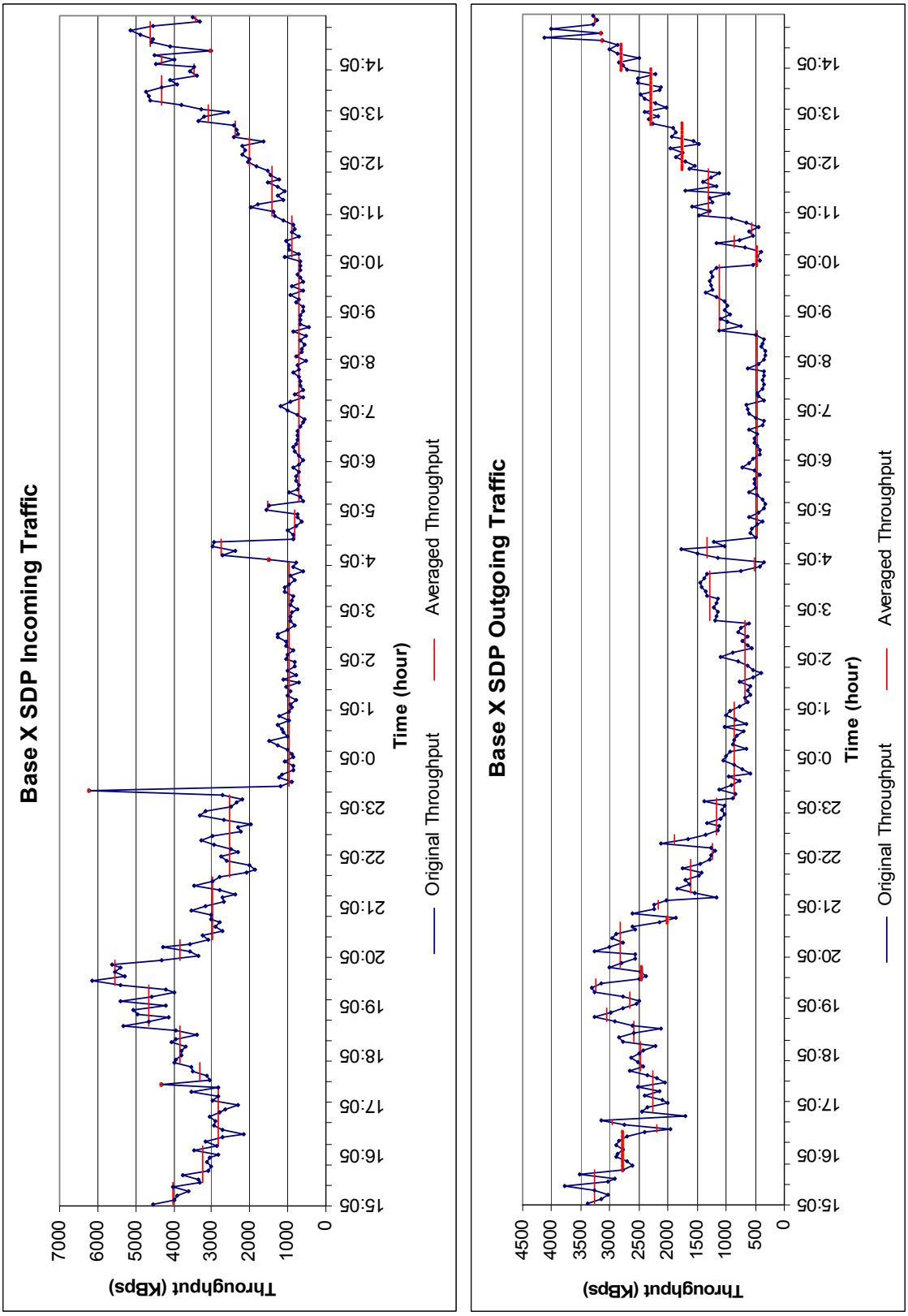
Appendix B: Acronym List

Acronym	Stands for
AF	Air Force
ARIS	Architecture of Integrated Information Systems
COTS	Commercial-Off-the-Shelf
CSFs	Critical Success Factors
DCPDS	Defense Civilian Personnel Data System
DEAMS	Defense Enterprise Accounting Management System
DEM	Dynamic Enterprise Modeling
DFAS	Defense Finance and Accounting Service
DIMHRS	Defense Integrated Military Human Resources System
DMHRSi	Defense Military Human Resources System - internet
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
ECSS	Expeditionary Combat Support system
ERP	Enterprise Resource Planning
ETP	Enterprise Transition Plan
FOC	Fully Operation Capable
GCSS	Global Combat Support System
GCSS-AF ESB	Global Combat Support System - Air Force Enterprise Service Bus
GFEBS	General Fund Enterprise Business System
IT	Information Technology
KBps	Kilobytes per second
LAN	Local Area Network
LMP	Logistics Modernization Program
Mbps	Megabits per second
MBps	Megabytes per second
OV	Operational View
PCMS	Personnel Claims Management System
PLM+	Product Lifecycle Management Plus
SDP	Service Delivery Point
SV	Systems/Services View
TRANSCOM (USTC)	Unites States Transportation Command
TV	Technical Standards View
URL	USAMA's (Army Medical Research and Material Command) Revolution in Logistics
WAN	Wide Area Network

Appendix C: Averaged SDP Throughput Charts






Base X SDP Incoming Traffic
Throughput (KBps)
7000
6000
5000
4000
3000
2000
1000
0
15:05
16:05
17:05
18:05
19:05
20:05
21:05
22:05
23:05
0:05
1:05
2:05
3:05
4:05
5:05
6:05
7:05
8:05
9:05
10:05
11:05
12:05
13:05
14:05
Time (hour)
Original Throughput
Averaged Throughput
Base X SDP Outgoing Traffic
Throughput (KBps)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
15:05
16:05
17:05
18:05
19:05
20:05
21:05
22:05
23:05
0:05
1:05
2:05
3:05
4:05
5:05
6:05
7:05
8:05
9:05
10:05
11:05
12:05
13:05
14:05
Time (hour)
Original Throughput
Averaged Throughput

Appendix D: Filler Traffic Input Data

Base Y Incoming Filler Traffic Input Data (1 entity = 100 packets)				
Time (sec)	Current workload interarrival (ms)	10% increase interarrival rate (ms)	20% increase interarrival rate (ms)	30% increase interarrival rate (ms)
0	68.7908	62.5371	57.3257	52.9160
9000	62.4759	56.7963	52.0633	48.0584
13800	46.5503	42.3184	38.7919	35.8079
18000	69.8779	63.5254	58.2316	53.7523
21900	46.6251	42.3865	38.8543	35.8655
24600	37.4663	34.0603	31.2219	28.8202
28200	29.6326	26.9387	24.6938	22.7943
29100	21.8740	19.8855	18.2283	16.8262
31800	25.2834	22.9849	21.0695	19.4488
35100	22.0457	20.0416	18.3714	16.9582
36300	24.1669	21.9699	20.1391	18.5899
36900	19.6074	17.8249	16.3395	15.0826
38100	23.0359	20.9418	19.1966	17.7200
40800	25.0040	22.7309	20.8366	19.2338
41700	28.1371	25.5792	23.4476	21.6439
48600	25.1637	22.8761	20.9697	19.3567
49200	21.6005	19.6369	18.0004	16.6158
49500	19.4898	17.7180	16.2415	14.9921
50400	17.8279	16.2072	14.8566	13.7138
55200	16.8994	15.3631	14.0828	12.9996
56100	24.3276	22.1160	20.2730	18.7135
57300	26.7871	24.3519	22.3226	20.6055
57600	36.2880	32.9891	30.2400	27.9138
60900	52.5378	47.7617	43.7815	40.4137
63900	42.8650	38.9682	35.7209	32.9731
65400	31.1339	28.3036	25.9449	23.9492
67200	47.8901	43.5365	39.9084	36.8386
69000	48.0847	43.7134	40.0706	36.9882
70800	49.6120	45.1018	41.3433	38.1630
72000	41.1091	37.3719	34.2576	31.6224
73200	62.9221	57.2019	52.4351	48.4016
74700	48.1242	43.7492	40.1035	37.0186
75300	68.0969	61.9063	56.7474	52.3822
78600	47.1006	42.8187	39.2505	36.2312
82200	60.9970	55.4518	50.8308	46.9208
83400	68.7631	62.5119	57.3026	52.8947
95400	62.4759	56.7963	52.0633	48.0584
100200	46.5503	42.3184	38.7919	35.8079
104400	69.8779	63.5254	58.2316	53.7523
108300	46.6251	42.3865	38.8543	35.8655

111000	37.4663	34.0603	31.2219	28.8202
114600	29.6326	26.9387	24.6938	22.7943
115500	21.8740	19.8855	18.2283	16.8262
118200	25.2834	22.9849	21.0695	19.4488
121500	22.0457	20.0416	18.3714	16.9582
122400	22.0457	20.0416	18.3714	16.9582

Base Y Outgoing Filler Traffic Input Data (1 entity = 100 packets)				
Time (sec)	**Current workload interarrival (ms)**	**10% increase interarrival rate (ms)**	**20% increase interarrival rate (ms)**	**30% increase interarrival rate (ms)**
0	129.8860	118.0782	108.2384	99.9123
6300	82.4084	74.9168	68.6737	63.3911
11400	110.8641	100.7855	92.3867	85.2801
16200	88.7501	80.6819	73.9584	68.2693
17100	107.4746	97.7042	89.5622	82.6728
18600	124.9245	113.5677	104.1038	96.0958
20700	172.6167	156.9243	143.8472	132.7821
21900	116.0560	105.5055	96.7134	89.2739
25800	58.8885	53.5350	49.0738	45.2989
27600	43.8694	39.8812	36.5578	33.7457
29700	40.8754	37.1594	34.0628	31.4426
31800	47.7912	43.4465	39.8260	36.7625
32400	57.7599	52.5090	48.1333	44.4307
33300	37.0936	33.7215	30.9114	28.5336
33900	57.7511	52.5010	48.1259	44.4239
34200	40.6991	36.9992	33.9160	31.3070
34500	25.6500	23.3182	21.3750	19.7308
34800	51.6363	46.9421	43.0303	39.7203
35700	62.1399	56.4908	51.7833	47.7999
36300	72.0303	65.4821	60.0253	55.4079
38400	56.1764	51.0694	46.8136	43.2126
39300	82.8462	75.3148	69.0385	63.7279
40800	61.9364	56.3058	51.6137	47.6434
42300	45.5014	41.3649	37.9178	35.0011
43200	31.2722	28.4293	26.0602	24.0555
44700	65.0966	59.1788	54.2472	50.0743
46500	44.3813	40.3466	36.9844	34.1395
48000	25.6140	23.2855	21.3450	19.7031
48300	18.2988	16.6353	15.2490	14.0760
48900	32.6523	29.6839	27.2102	25.1171
49800	26.7787	24.3443	22.3156	20.5990
50100	19.8052	18.0047	16.5043	15.2348
51300	22.6153	20.5594	18.8461	17.3964
51600	28.5560	25.9600	23.7967	21.9662
54300	20.4108	18.5553	17.0090	15.7006
54900	17.4973	15.9067	14.5811	13.4595
56400	22.5386	20.4897	18.7822	17.3374

57300	31.1066	28.2788	25.9222	23.9282
58200	20.9970	19.0882	17.4975	16.1515
58500	29.3155	26.6505	24.4296	22.5504
59700	44.2684	40.2440	36.8904	34.0526
61500	50.3496	45.7723	41.9580	38.7304
62700	59.1045	53.7313	49.2537	45.4650
66600	73.7513	67.0466	61.4594	56.7318
67200	110.7679	100.6981	92.3066	85.2061
68100	161.8898	147.1725	134.9081	124.5306
86400	129.8860	118.0782	108.2384	99.9123
92700	82.4084	74.9168	68.6737	63.3911
97800	110.8641	100.7855	92.3867	85.2801
102600	88.7501	80.6819	73.9584	68.2693
103500	107.4746	97.7042	89.5622	82.6728
105000	124.9245	113.5677	104.1038	96.0958
107100	172.6167	156.9243	143.8472	132.7821
108300	116.0560	105.5055	96.7134	89.2739
112200	58.8885	53.5350	49.0738	45.2989
114000	43.8694	39.8812	36.5578	33.7457
116100	40.8754	37.1594	34.0628	31.4426
118200	47.7912	43.4465	39.8260	36.7625
118800	57.7599	52.5090	48.1333	44.4307
119700	37.0936	33.7215	30.9114	28.5336
120300	57.7511	52.5010	48.1259	44.4239
120600	40.6991	36.9992	33.9160	31.3070
120900	25.6500	23.3182	21.3750	19.7308
121200	51.6363	46.9421	43.0303	39.7203
122100	62.1399	56.4908	51.7833	47.7999
122400	62.1399	56.4908	51.7832	47.7999

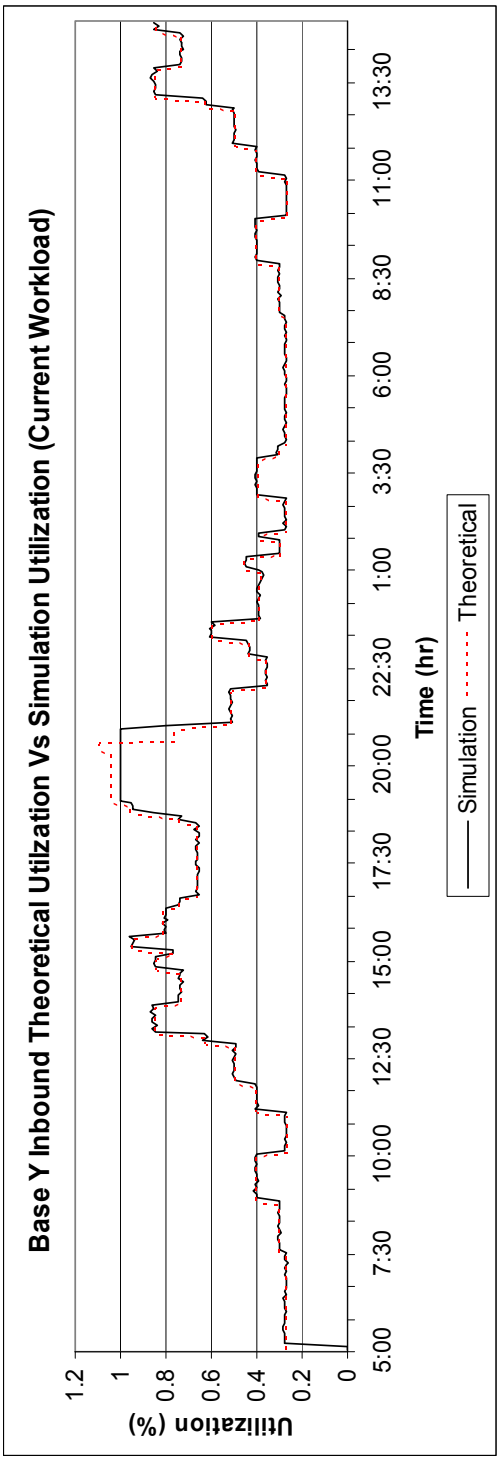
Base X Incoming Filler Traffic Input Data (1 entity = 100 packets)				
Time (sec)	**Current workload interarrival (ms)**	**10% increase interarrival rate (ms)**	**20% increase interarrival rate (ms)**	**30% increase interarrival rate (ms)**
0	124.8862	113.5329	104.0718	96.0663
300	65.5855	59.6232	54.6546	50.4504
900	138.8649	126.2408	115.7207	106.8192
18600	109.6455	99.6777	91.3712	84.3427
21600	70.6900	64.2636	58.9083	54.3769
25200	49.9334	45.3940	41.6111	38.4103
27300	42.1356	38.3051	35.1130	32.4120
28500	32.3002	29.3638	26.9168	24.8463
29700	23.2486	21.1351	19.3739	17.8836
31800	28.8102	26.1911	24.0085	22.1617
32700	23.0945	20.9950	19.2454	17.7650
33600	33.1624	30.1476	27.6353	25.5095
33900	21.6042	19.6402	18.0035	16.6186
35700	29.3019	26.6381	24.4183	22.5399

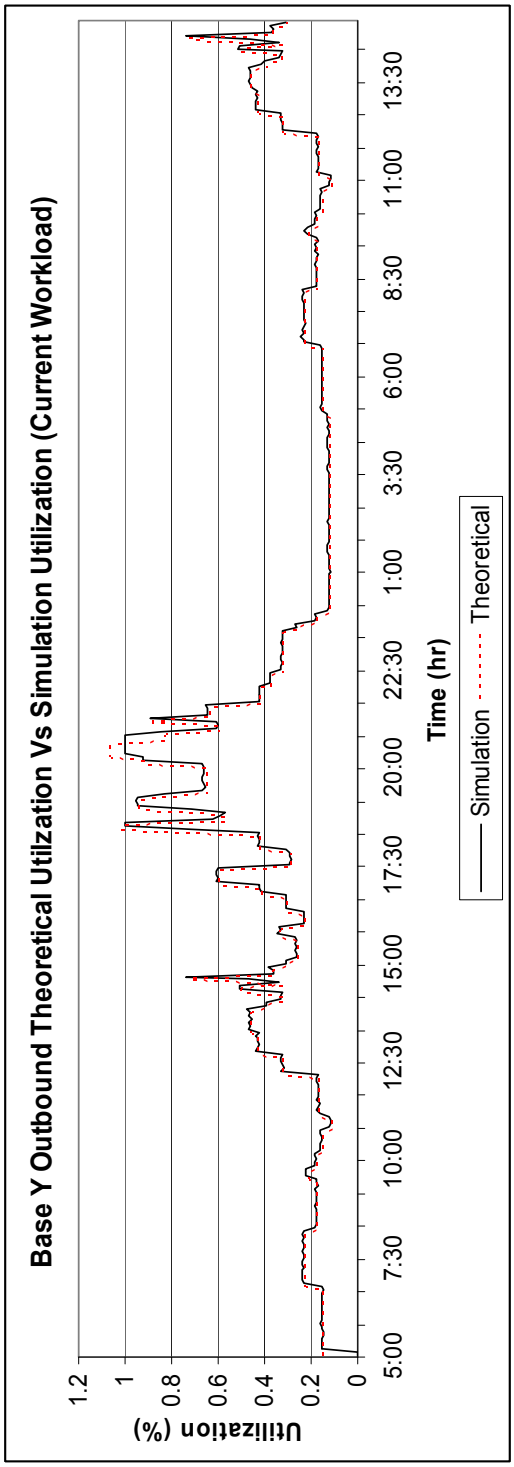
36300	24.9141	22.6492	20.7618	19.1647
37800	31.0110	28.1918	25.8425	23.8546
40500	35.3880	32.1709	29.4900	27.2216
45000	23.1356	21.0324	19.2797	17.7966
45300	30.2425	27.4932	25.2021	23.2634
46500	26.0648	23.6952	21.7206	20.0498
49200	21.4804	19.5276	17.9003	16.5234
52200	17.9818	16.3471	14.9848	13.8322
54000	26.1922	23.8111	21.8268	20.1478
55500	33.7152	30.6502	28.0960	25.9348
60000	39.2082	35.6438	32.6735	30.1602
66300	16.0723	14.6111	13.3936	12.3633
66600	102.1160	92.8327	85.0967	78.5508
83100	67.8407	61.6734	56.5340	52.1852
83400	36.3454	33.0413	30.2879	27.9580
84600	124.8862	113.5329	104.0718	96.0663
86700	65.5855	59.6232	54.6546	50.4504
87300	138.8649	126.2408	115.7207	106.8192
105000	109.6455	99.6777	91.3712	84.3427
108000	70.6900	64.2636	58.9083	54.3769
111600	49.9334	45.3940	41.6111	38.4103
113700	42.1356	38.3051	35.1130	32.4120
114900	32.3002	29.3638	26.9168	24.8463
116100	23.2486	21.1351	19.3739	17.8836
118200	28.8102	26.1911	24.0085	22.1617
119100	23.0945	20.9950	19.2454	17.7650
120000	33.1624	30.1476	27.6353	25.5095
120300	21.6042	19.6402	18.0035	16.6186
122100	29.3019	26.6381	24.4183	22.5399
122400	29.3019	26.6381	24.4183	22.5399

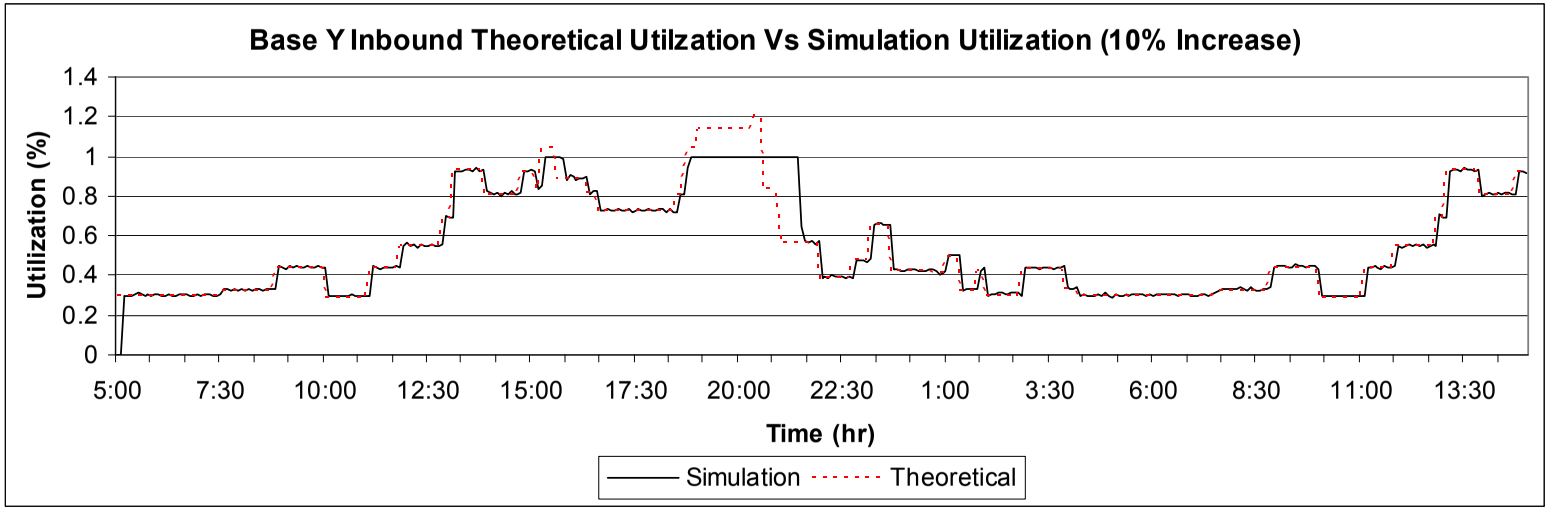
Base X Outgoing Filler Traffic Input Data (1 entity = 100 packets)				
Time (sec)	**Current workload interarrival (ms)**	**10% increase interarrival rate (ms)**	**20% increase interarrival rate (ms)**	**30% increase interarrival rate (ms)**
0	215.6976	196.0887	179.7480	165.9212
13200	89.5097	81.3724	74.5914	68.8536
18000	219.1972	199.2702	182.6643	168.6132
19200	114.9440	104.4946	95.7867	88.4185
20100	178.7957	162.5416	148.9965	137.5352
21300	110.2584	100.2349	91.8820	84.8142
21600	75.9185	69.0169	63.2655	58.3989
24900	57.3108	52.1007	47.7590	44.0852
28200	43.5927	39.6297	36.3272	33.5328
32100	35.8579	32.5981	29.8816	27.5830
34200	31.9291	29.0264	26.6075	24.5608
34500	24.1958	21.9962	20.1632	18.6121
34800	31.7594	28.8721	26.4661	24.4303

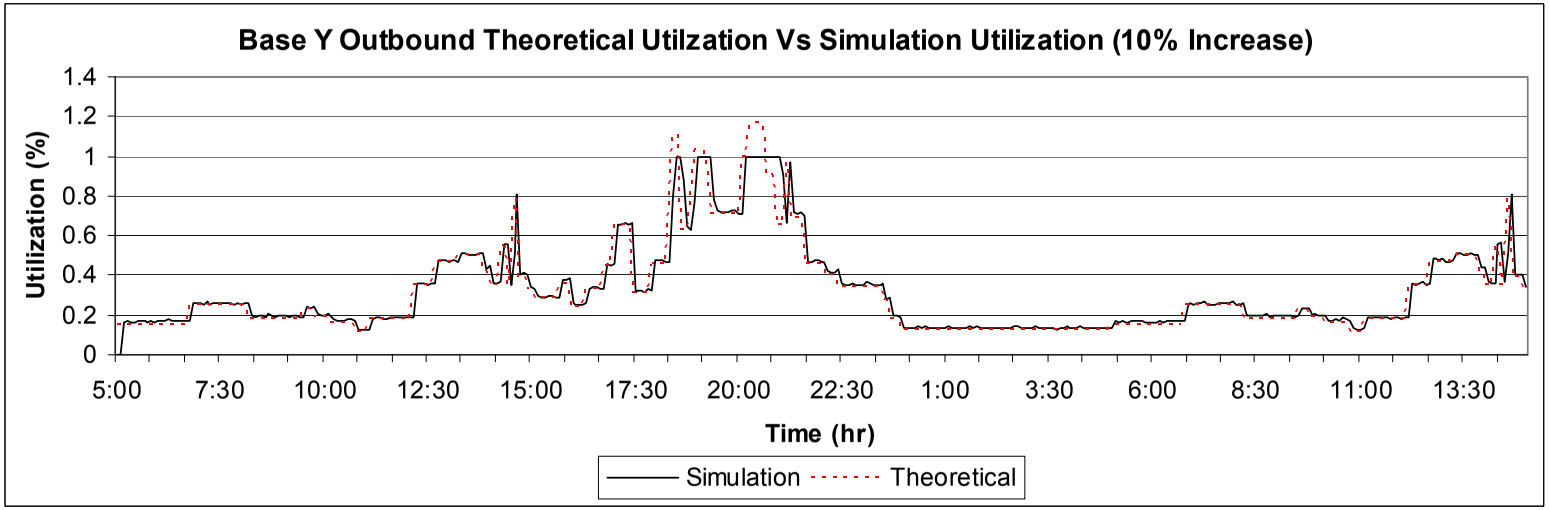
35100	24.9568	22.6880	20.7973	19.1975
35400	30.6962	27.9057	25.5802	23.6125
36300	30.6534	27.8667	25.5445	23.5795
38700	35.9089	32.6444	29.9241	27.6222
41400	45.7327	41.5752	38.1106	35.1790
42000	33.8828	30.8025	28.2357	26.0637
42600	58.6536	53.3215	48.8780	45.1182
42900	44.2956	40.2688	36.9130	34.0736
45900	40.2881	36.6256	33.5734	30.9909
48000	38.6485	35.1350	32.2071	29.7296
49500	32.6885	29.7169	27.2405	25.1450
50400	37.6995	34.2722	31.4162	28.9996
51600	30.9082	28.0983	25.7568	23.7755
52500	40.8440	37.1309	34.0367	31.4185
53400	35.4708	32.2462	29.5590	27.2852
56700	49.8025	45.2750	41.5021	38.3096
57300	38.2192	34.7448	31.8494	29.3994
57600	46.3292	42.1174	38.6076	35.6378
58500	85.2345	77.4859	71.0287	65.5650
58800	62.5326	56.8479	52.1105	48.1020
61200	80.5824	73.2568	67.1520	61.9865
62400	53.1481	48.3165	44.2901	40.8832
63000	85.2379	77.4890	71.0315	65.5676
65700	116.3751	105.7956	96.9793	89.5193
72600	148.6639	135.1490	123.8866	114.3569
78600	78.4471	71.3155	65.3725	60.3439
82200	195.5886	177.8079	162.9905	150.4528
83100	75.0577	68.2343	62.5481	57.7367
84600	215.6976	196.0887	179.7480	165.9212
99600	89.5097	81.3724	74.5914	68.8536
104400	219.1972	199.2702	182.6643	168.6132
105600	114.9440	104.4946	95.7867	88.4185
106500	178.7957	162.5416	148.9965	137.5352
107700	110.2584	100.2349	91.8820	84.8142
108000	75.9185	69.0169	63.2655	58.3989
111300	57.3108	52.1007	47.7590	44.0852
114600	43.5927	39.6297	36.3272	33.5328
118500	35.8579	32.5981	29.8816	27.5830
120600	31.9291	29.0264	26.6075	24.5608
120900	24.1958	21.9962	20.1632	18.6121
121200	31.7594	28.8721	26.4661	24.4303
121500	24.9568	22.6880	20.7973	19.1975
121800	30.6962	27.9057	25.5802	23.6125
122400	30.6962	27.9057	25.5802	23.6125

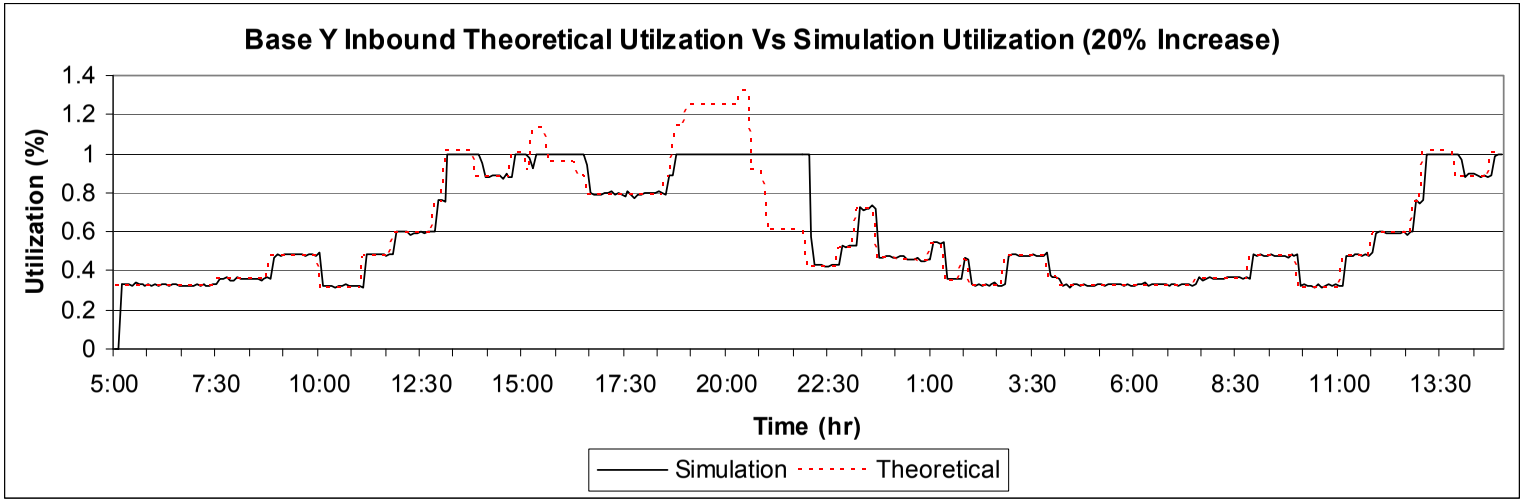
Appendix E: Theoretical Utilization and Simulation Utilization Charts

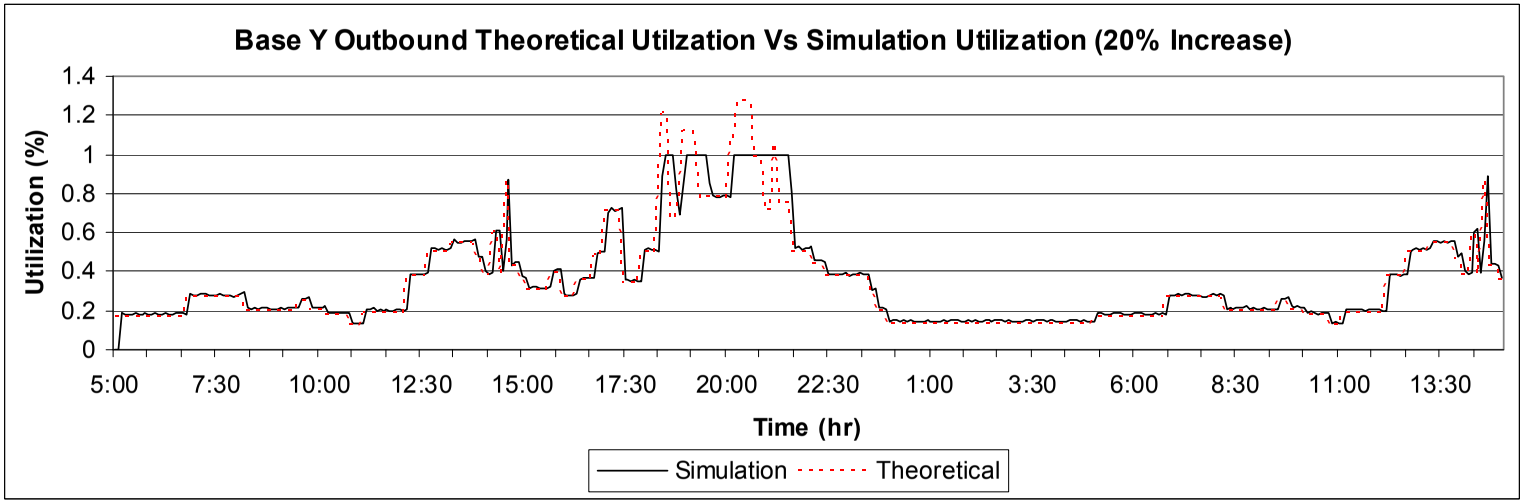


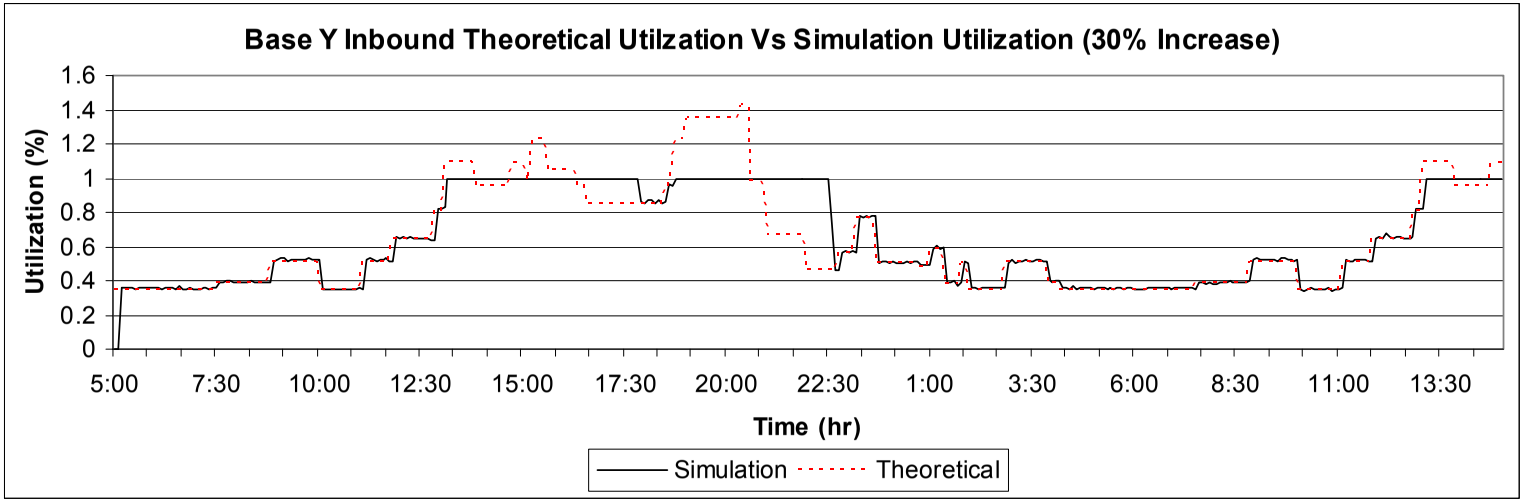


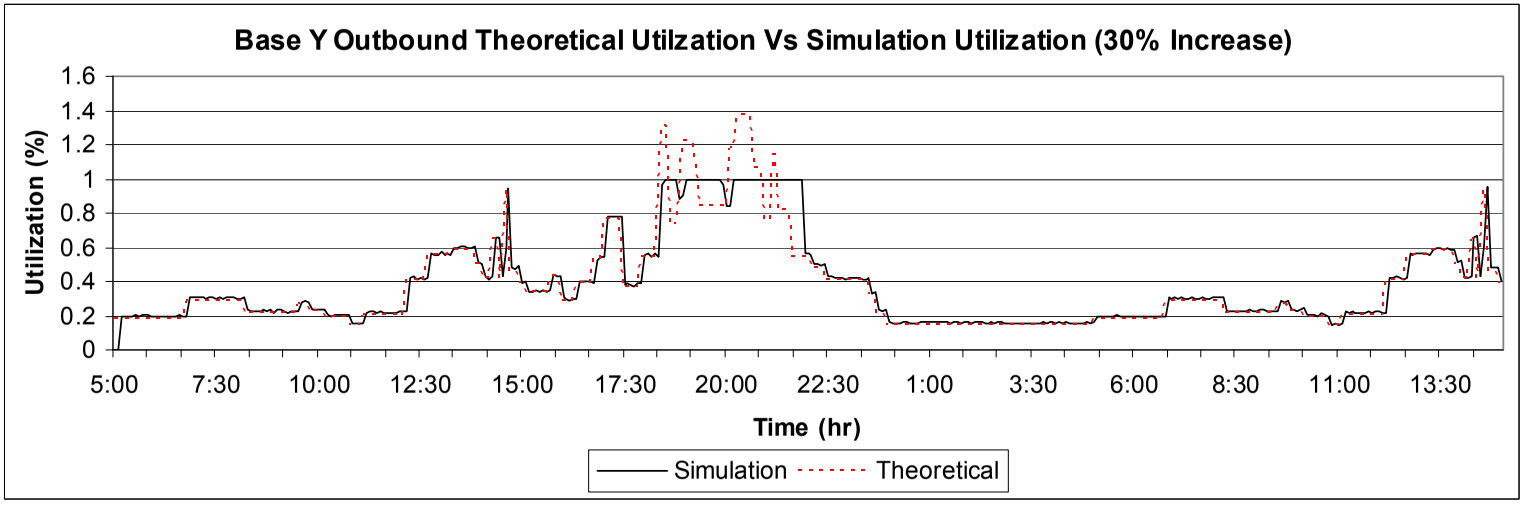

Base Y Inbound Theoretical Utilzation Vs Simulation Utilization (10% Increase)
Utilization (%)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5:00
7:30
10:00
12:30
15:00
17:30
20:00
22:30
1:00
3:30
6:00
8:30
11:00
13:30
Time (hr)
Simulation
Theoretical


Base Y Outbound Theoretical Utilzation Vs Simulation Utilization (10% Increase)
Utilization (%)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5:00
7:30
10:00
12:30
15:00
17:30
20:00
22:30
1:00
3:30
6:00
8:30
11:00
13:30
Time (hr)
Simulation
Theoretical

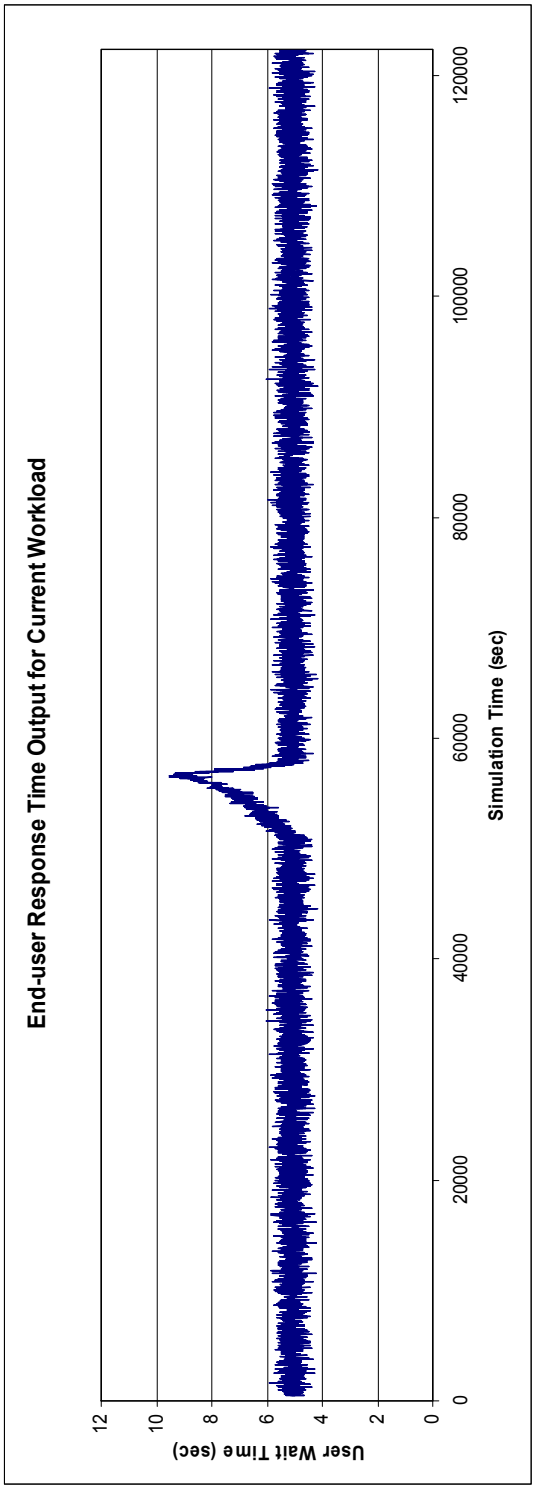

Base Y Inbound Theoretical Utilzation Vs Simulation Utilization (20% Increase)
Utilization (%)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5:00
7:30
10:00
12:30
15:00
17:30
20:00
22:30
1:00
3:30
6:00
8:30
11:00
13:30
Time (hr)
Simulation
Theoretical

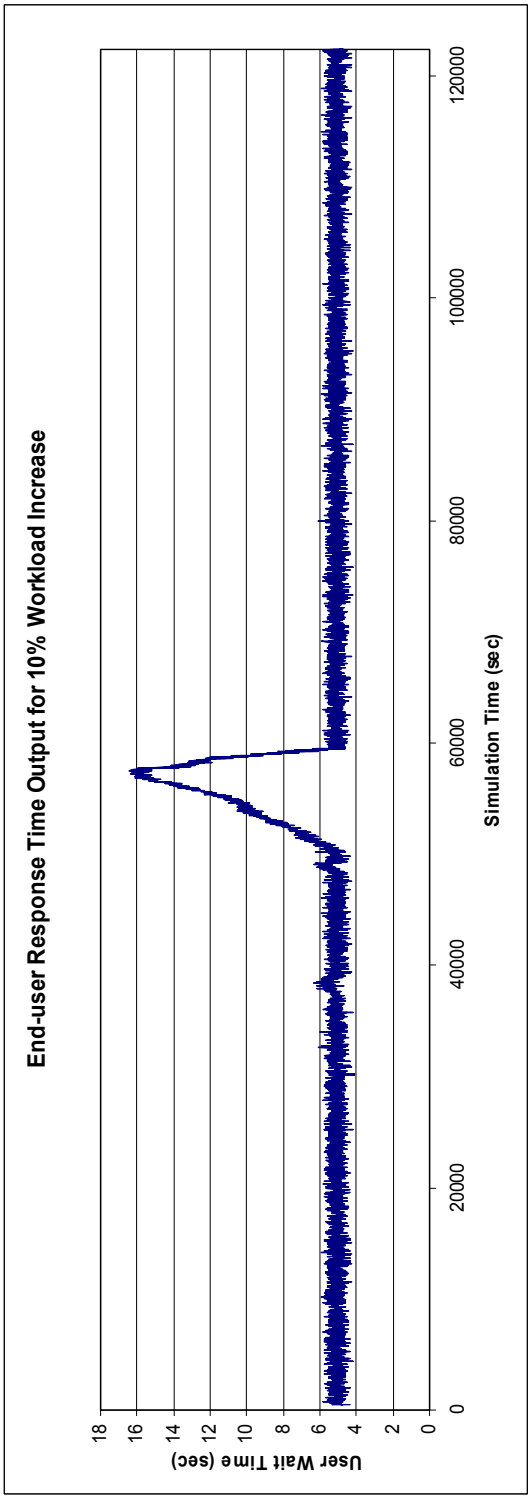

Base Y Outbound Theoretical Utilzation Vs Simulation Utilization (20% Increase)
Utilization (%)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5:00
7:30
10:00
12:30
15:00
17:30
20:00
22:30
1:00
3:30
6:00
8:30
11:00
13:30
Time (hr)
Simulation
Theoretical

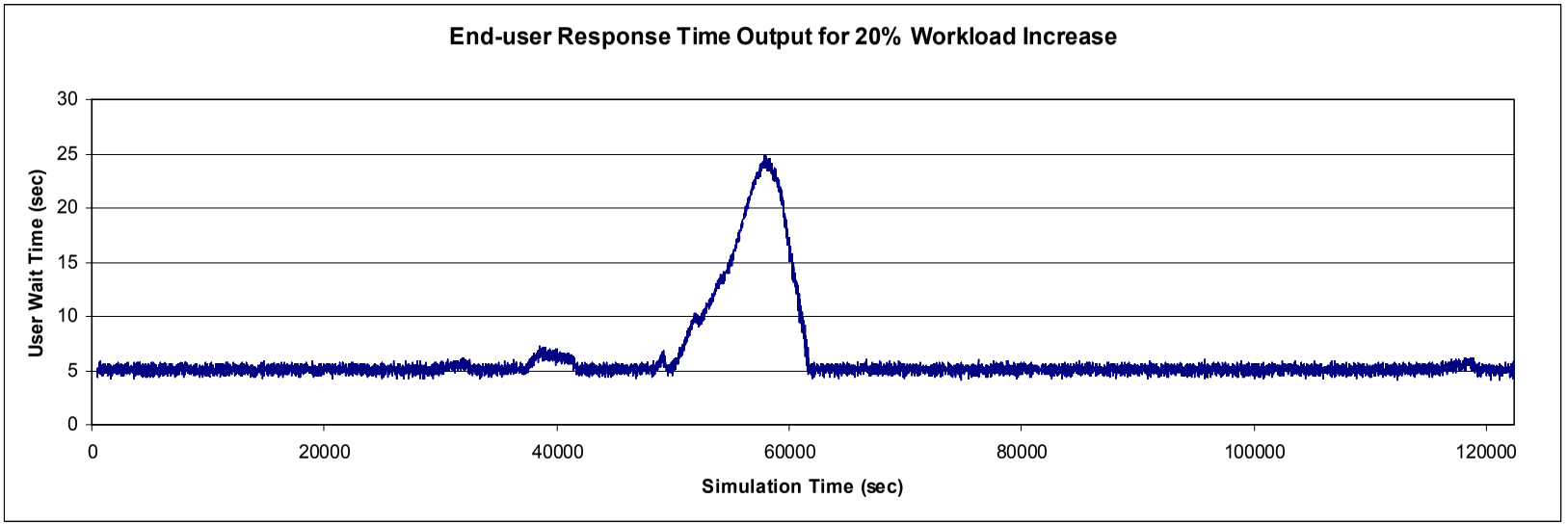

Base Y Inbound Theoretical Utilzation Vs Simulation Utilization (30% Increase)
Utilization (%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5:00
7:30
10:00
12:30
15:00
17:30
20:00
22:30
1:00
3:30
6:00
8:30
11:00
13:30
Time (hr)
Simulation
Theoretical

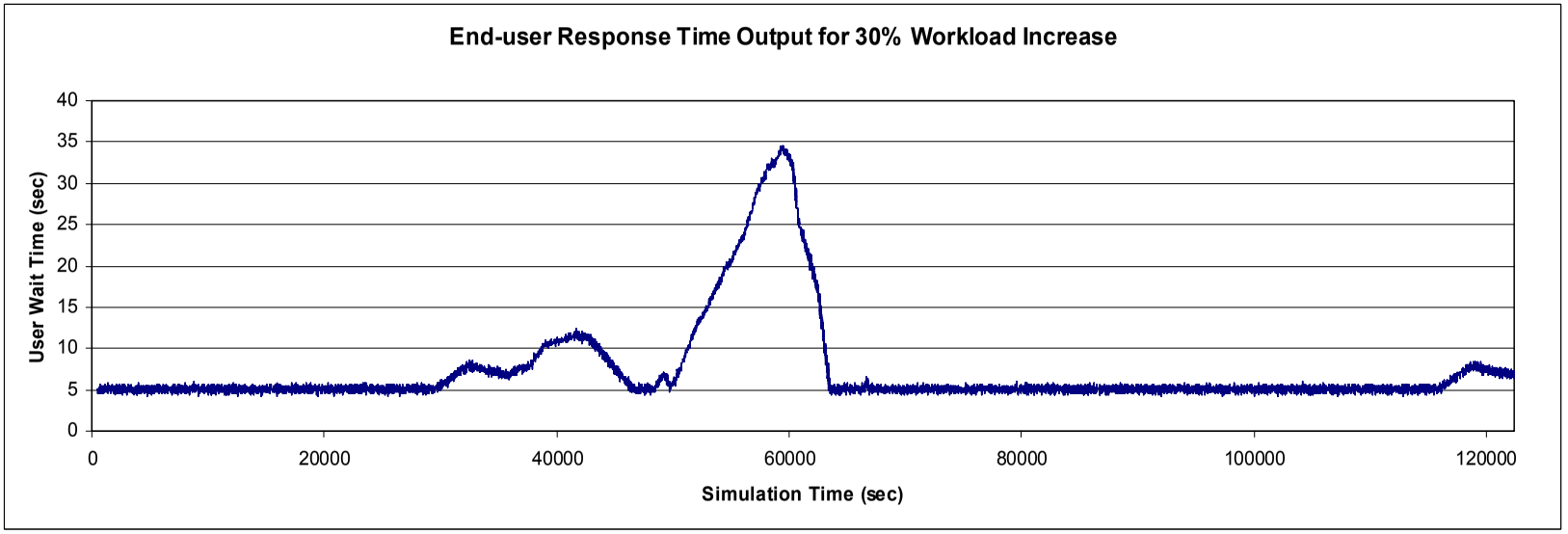

Base Y Outbound Theoretical Utilzation Vs Simulation Utilization (30% Increase)
Utilization (%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5:00
7:30
10:00
12:30
15:00
17:30
20:00
22:30
1:00
3:30
6:00
8:30
11:00
13:30
Time (hr)
Simulation
Theoretical

Appendix F: Single Simulation Run Response Time Output






End-user Response Time Output for 20% Workload Increase
User Wait Time (sec)
30
25
20
15
10
5
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)


End-user Response Time Output for 30% Workload Increase
User Wait Time (sec)
40
35
30
25
20
15
10
5
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

Appendix G: Excel VBA Code

```
Sub FormatInputData()
'  This macro extracts the data value from a string and changes the format from scientific
' notation to standard number format. The inbound and outbound traffic values were
' provided in the following format:
' Date and Time, “inbound throughput”, “outbound throughput”

Dim i, j As Integer
Dim str, str2, str3 As String

'Loop through every line of data in the worksheet
For i = 0 To 300
   str = Range("A14").Offset(i, 0).Text
   j = Len(str)

   'Extract the inbound value and write to the worksheet
   str2 = Left(str, 37)
   str3 = Right(str2, 16)
   Range("I14").Offset(i, 0).Value = str3

   'Extract the outbound value and write to the worksheet
   str2 = Right(str, 17)
   str3 = Left(str2, 16)
   Range("M14").Offset(i, 0).Value = str3
Next

'Change the worksheet value format from scientific notation to standard number
Range("I14:I314").NumberFormat = "0"
Range("M14:M314").NumberFormat = "0"

End Sub


Sub ClearSheets()
' This macro clears all cells in all worksheets
' After all cells are cleared the macro re-enters the column headers
Dim i As Integer

   Sheets("WaitTime").Select
   Cells.Select
   Selection.ClearContents

   Range("A1").Select
   Selection.Value = "Run 0"
```

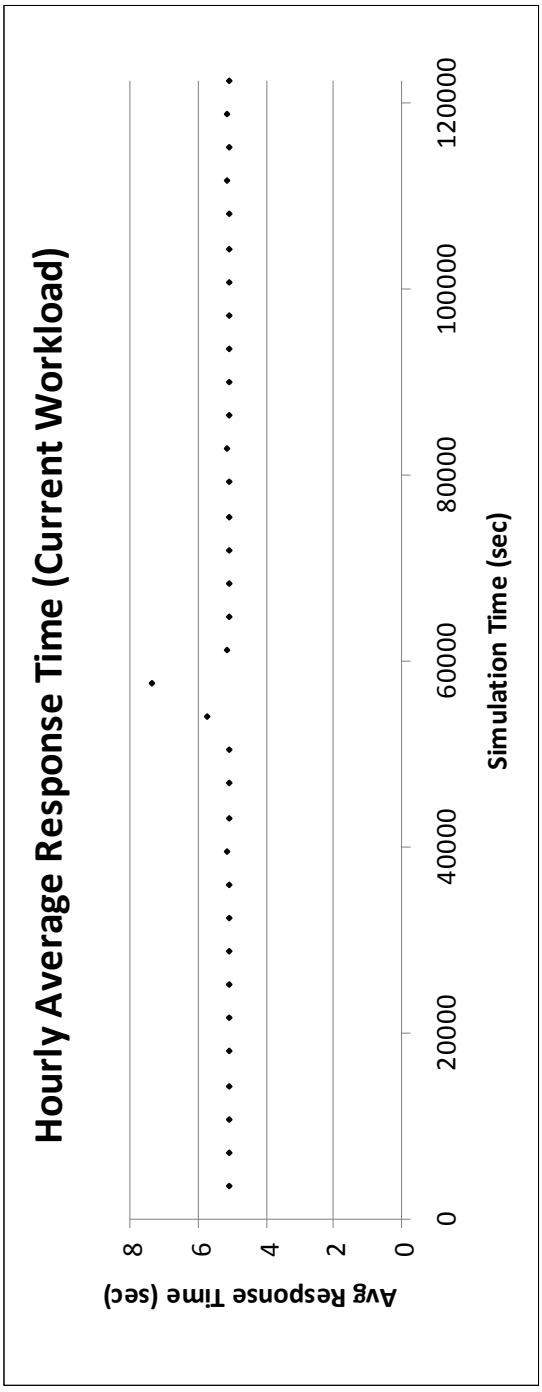
```
    Selection.Offset(1, 0).Value = "Sim Time"
    Selection.Offset(1, 1).Value = "Wait Time"

Sheets("Base Y Queue").Select
    Cells.Select
    Selection.ClearContents
    Range("A1").Select
    ActiveCell.FormulaR1C1 = "Block"
    Range("B1").Select
    ActiveCell.FormulaR1C1 = "Block Name"
    Range("C1").Select
    ActiveCell.FormulaR1C1 = "Ave Length"
    Range("D1").Select
    ActiveCell.FormulaR1C1 = "Max Length"
    Range("E1").Select
    ActiveCell.FormulaR1C1 = "Ave Wait"
    Range("F1").Select
    ActiveCell.FormulaR1C1 = "Max Wait"
    Range("G1").Select
    ActiveCell.FormulaR1C1 = "Queue Length"
    Range("H1").Select
    ActiveCell.FormulaR1C1 = "Arrivals"
    Range("I1").Select
    ActiveCell.FormulaR1C1 = "Departures"
    Range("J1").Select
    ActiveCell.FormulaR1C1 = "Reneges"
    Range("K1").Select
    ActiveCell.FormulaR1C1 = "Utilization"
    Range("L1").Select
    ActiveCell.FormulaR1C1 = "Time (sec)"
    Range("M1").Select
Sheets("Base X Queue").Select
    Cells.Select
    Selection.ClearContents
    Range("A1").Select
    ActiveCell.FormulaR1C1 = "Block"
    Range("B1").Select
    ActiveCell.FormulaR1C1 = "Block Name"
    Range("C1").Select
    ActiveCell.FormulaR1C1 = "Ave Length"
    Range("D1").Select
    ActiveCell.FormulaR1C1 = "Max Length"
    Range("E1").Select
    ActiveCell.FormulaR1C1 = "Ave Wait"
    Range("F1").Select
    ActiveCell.FormulaR1C1 = "Max Wait"
```

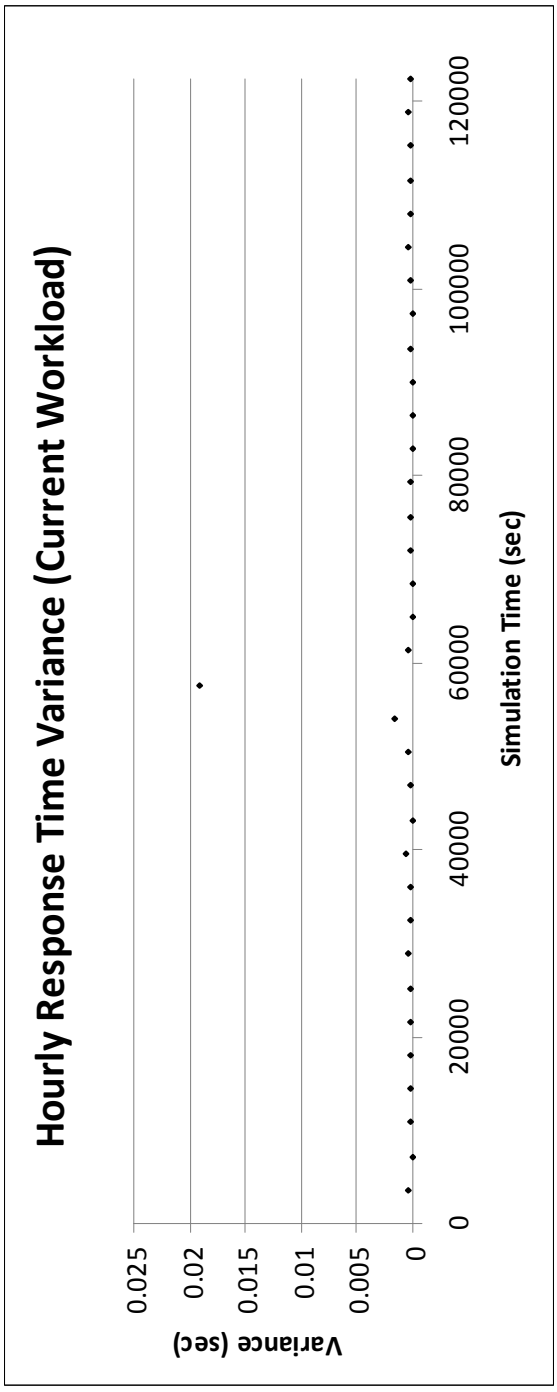
```
    Range("G1").Select
    ActiveCell.FormulaR1C1 = "Queue Length"
    Range("H1").Select
    ActiveCell.FormulaR1C1 = "Arrivals"
    Range("I1").Select
    ActiveCell.FormulaR1C1 = "Departures"
    Range("J1").Select
    ActiveCell.FormulaR1C1 = "Reneges"
    Range("K1").Select
    ActiveCell.FormulaR1C1 = "Utilization"
    Range("L1").Select
    ActiveCell.FormulaR1C1 = "Time (sec)"
    Range("M1").Select

Sheets("Resource").Select
    Cells.Select
    Selection.ClearContents
    Range("A1").Select
    ActiveCell.FormulaR1C1 = "Block"
    Range("B1").Select
    ActiveCell.FormulaR1C1 = "Block Name"
    Range("C1").Select
    ActiveCell.FormulaR1C1 = "Utilization"
    Range("D1").Select
    ActiveCell.FormulaR1C1 = "Departures"
    Range("E1").Select
    ActiveCell.FormulaR1C1 = "In Use"
    Range("F1").Select
    ActiveCell.FormulaR1C1 = "Items Waiting"
    Range("G1").Select
    ActiveCell.FormulaR1C1 = "Ave Items Waiting"
    Range("H1").Select
    ActiveCell.FormulaR1C1 = "Ave Wait Time"
    Range("I1").Select
    ActiveCell.FormulaR1C1 = "Time (sec)"
    Range("J1").Select

End Sub


Sub FormatResponseTimes()
' This macro calculates the response time by dividing the output by 100.
' This is done because the delay times correspond to an entity of 100 packets, thus the
' data provided by the simulation is response time per 100 packets

Dim str, str2 As String
```

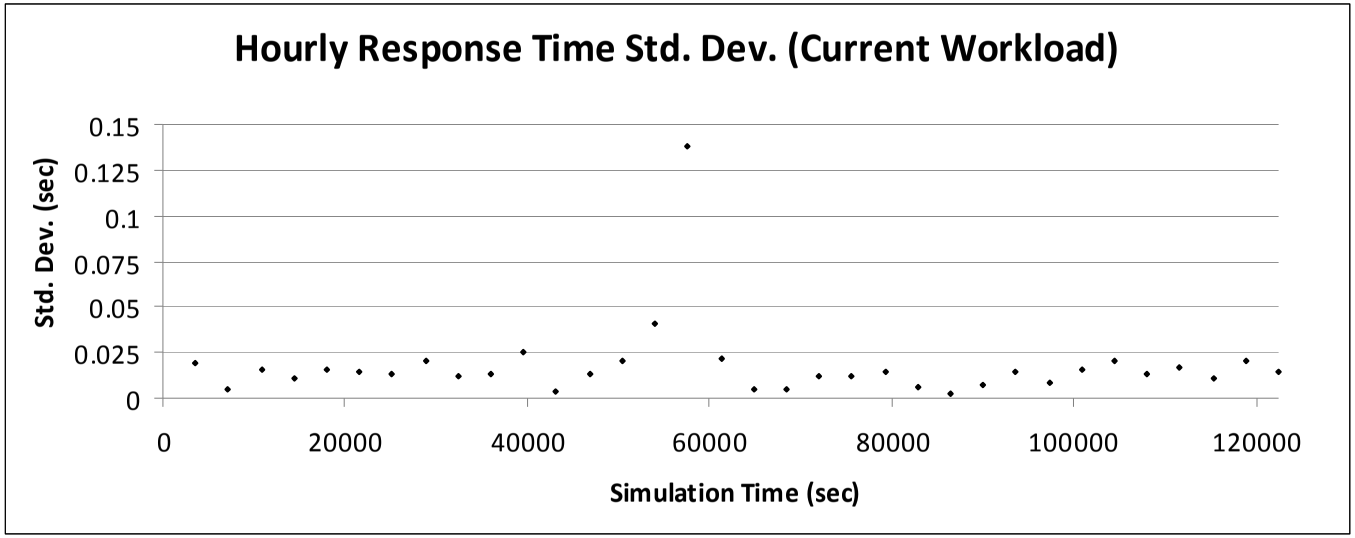
```
Dim rows As Integer

Range("B3").Select
rows = Range(Selection, Selection.End(xlDown)).Count + 2

Range("C3").Select
ActiveCell.FormulaR1C1 = "=RC[-1]/100"

str2 = "C3:C" & rows
Range("C3").Select
Selection.AutoFill Destination:=Range(str2), Type:=FillDefault
Range(str2).Select

End Sub


Sub calculateAverages()
'This macro fills the active worksheet with the hourly and 5-minute response time sums
and
'number of observations per category. This data is used by the formulas in the worksheet
to
'calculate the hourly and 5-minute averages

Dim i, j, rows, sum, numPoints As Integer
Dim simTime, responseTime As Double

Range("A3").Select
rows = Range(Selection, Selection.End(xlDown)).Count

'loop through all the response times
For i = 1 To rows

   simTime = Range("A2").Offset(i, 0).Value
   responseTime = Range("B2").Offset(i, 0).Value

   'loop through all the hour categories
   For j = 0 To 33
      If simTime >= j * 3600 And simTime < (j + 1) * 3600 Then
         'add the response time to the correct hour category
         Range("E3").Offset(j, 0).Value = Range("E3").Offset(j, 0).Value + responseTime
         'increment the number of observations in the corresponding hour category
         Range("E3").Offset(j, 1).Value = Range("E3").Offset(j, 1).Value + 1
      End If
   Next

   'loop through all the 5-minute categories
```

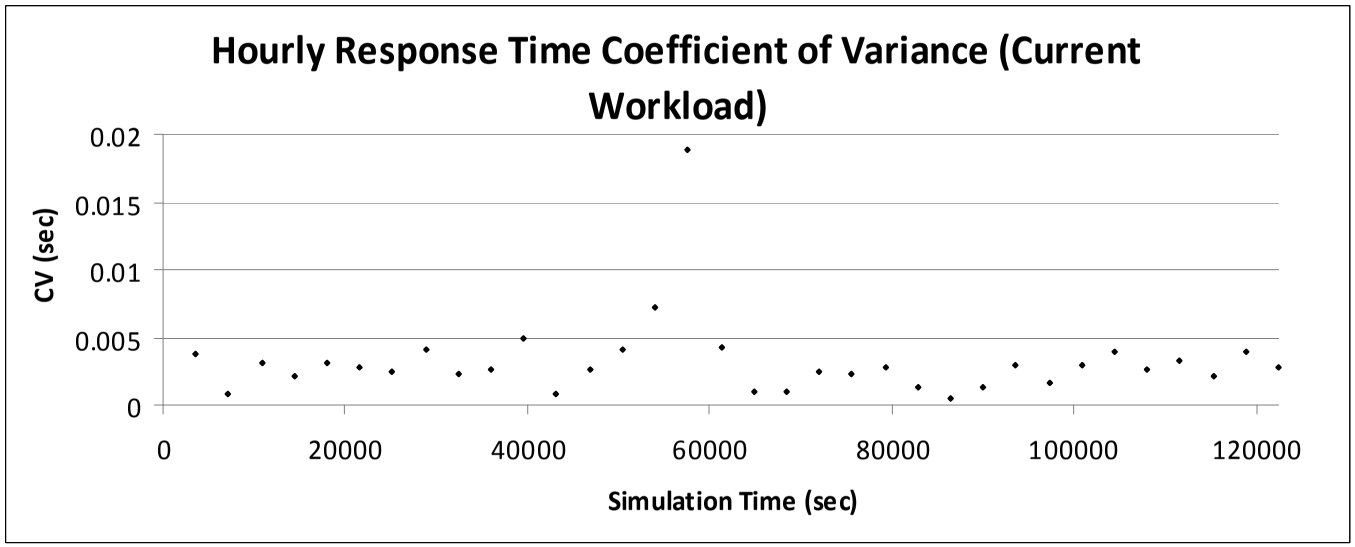
```
    For j = 0 To 407
        If simTime >= j * 300 And simTime < (j + 1) * 300 Then
            'add the response time to the correct 5-minute category
            Range("J3").Offset(j, 0).Value = Range("J3").Offset(j, 0).Value + responseTime
            'incrament the number of observations in the corresponding 5-minute category
            Range("J3").Offset(j, 1).Value = Range("J3").Offset(j, 1).Value + 1
        End If
    Next

Next
End Sub


Sub FormatOutgoingUtilizationData()
'This macro deletes the rows of data for the incoming SDP resource, leaving only the
'utilizations for the outgoing SDP resource

Dim i As Integer
Dim str As String

For i = 3 To 409
        str = i & ":" & i
        rows(str).Select
        Selection.Delete shift:=xlUp
Next
End Sub


Sub FormatIncomingUtilizationData()
'This macro deletes the rows of data for the outgoing SDP resource, leaving only the
'utilizations for the incoming SDP resource

Dim i As Integer
Dim str As String

rows("2:2").Select
Selection.Delete shift:=xlUp

For i = 3 To 409
    str = i & ":" & i
    rows(str).Select
    Selection.Delete shift:=xlUp
Next
End Sub
```

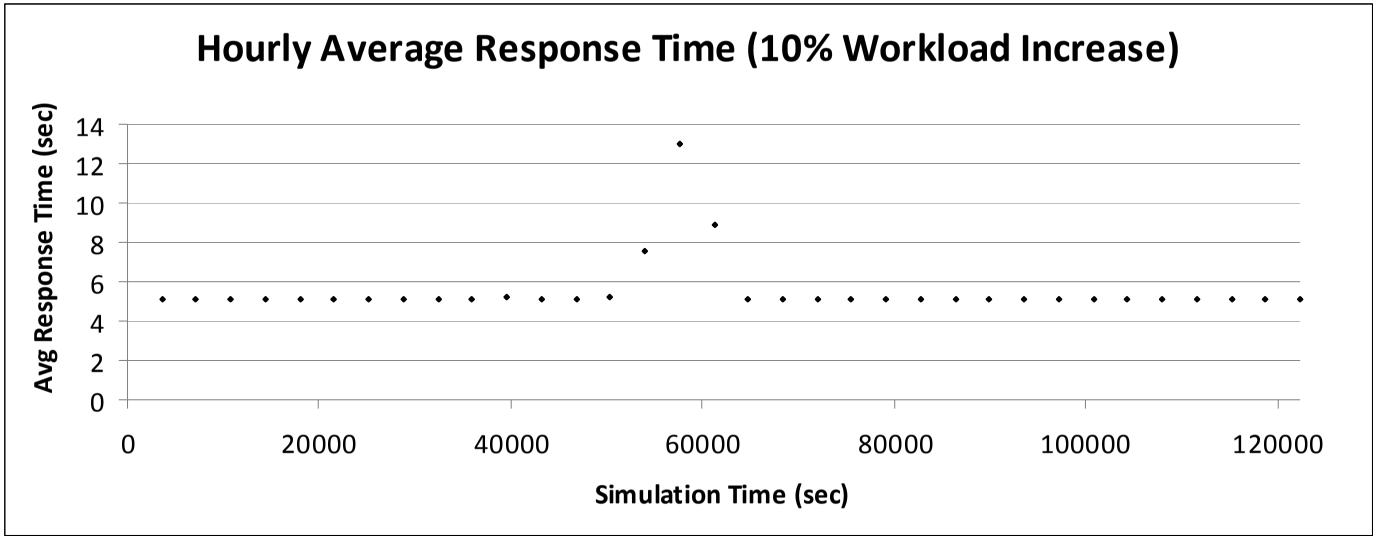
Appendix H: Hourly Average Response Time Charts

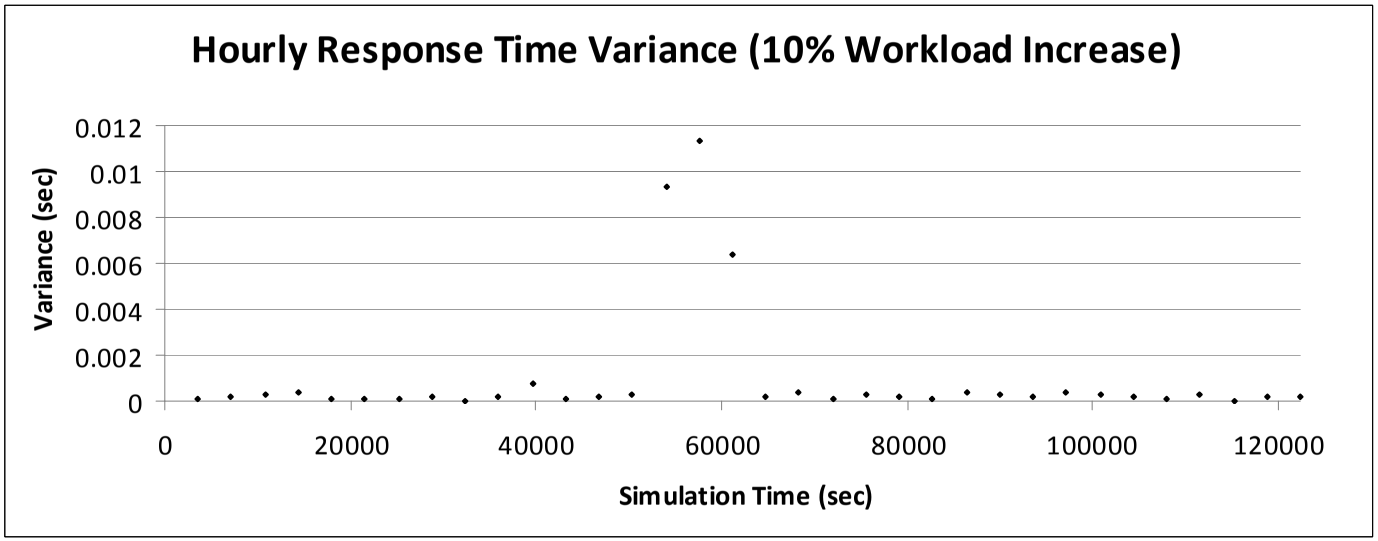


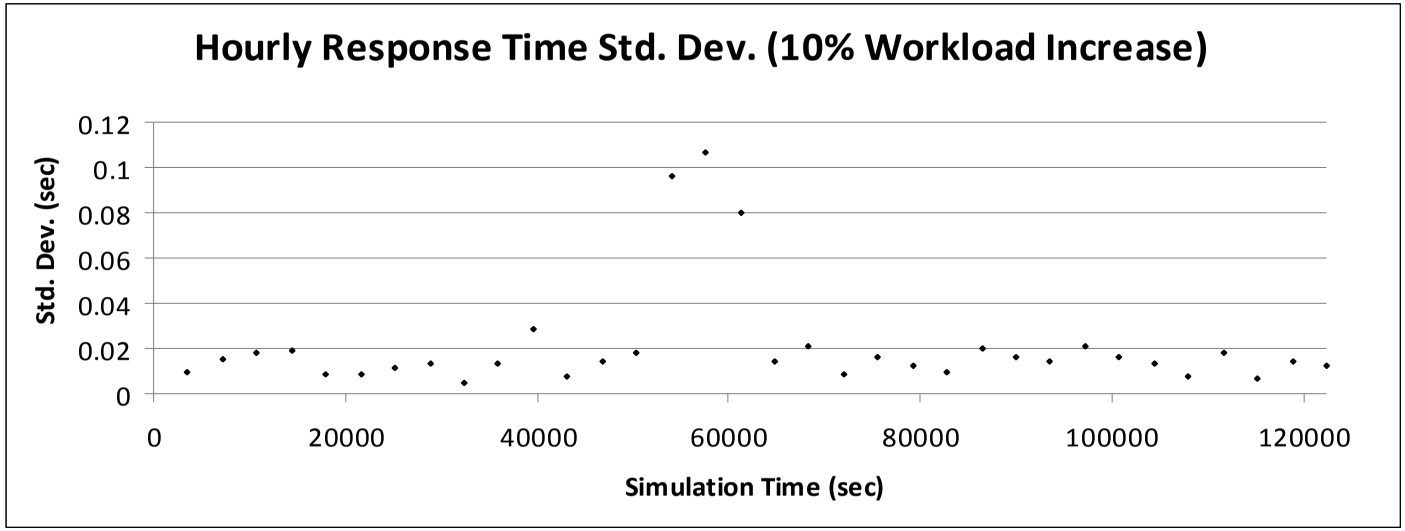


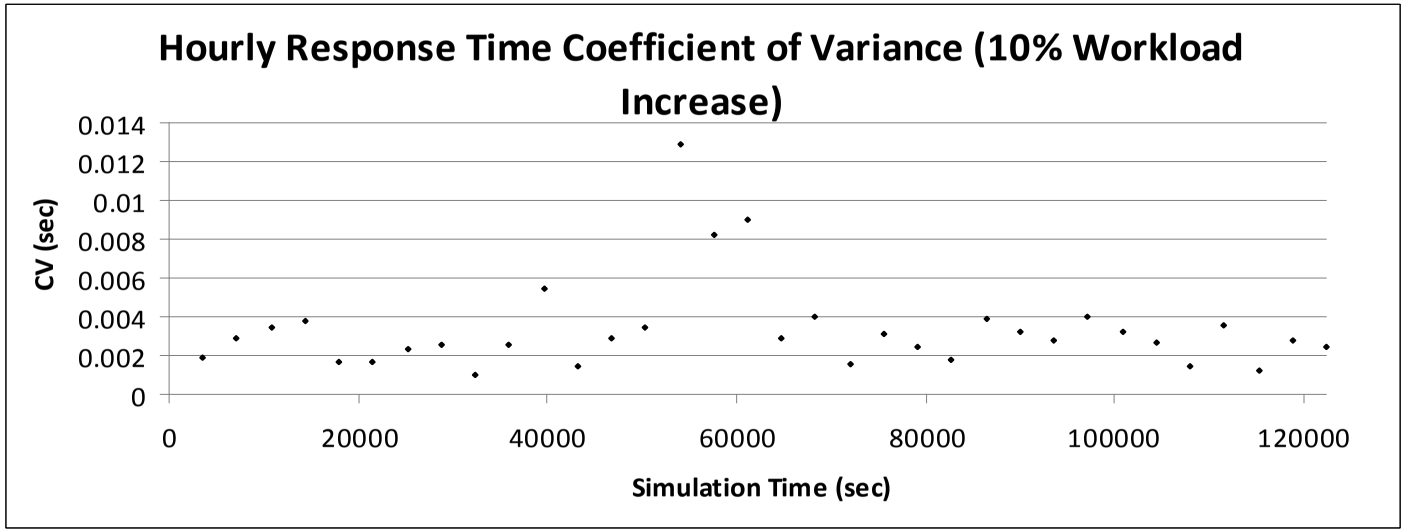

Hourly Response Time Std. Dev. (Current Workload)
Std. Dev. (sec)
0.15
0.125
0.1
0.075
0.05
0.025
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

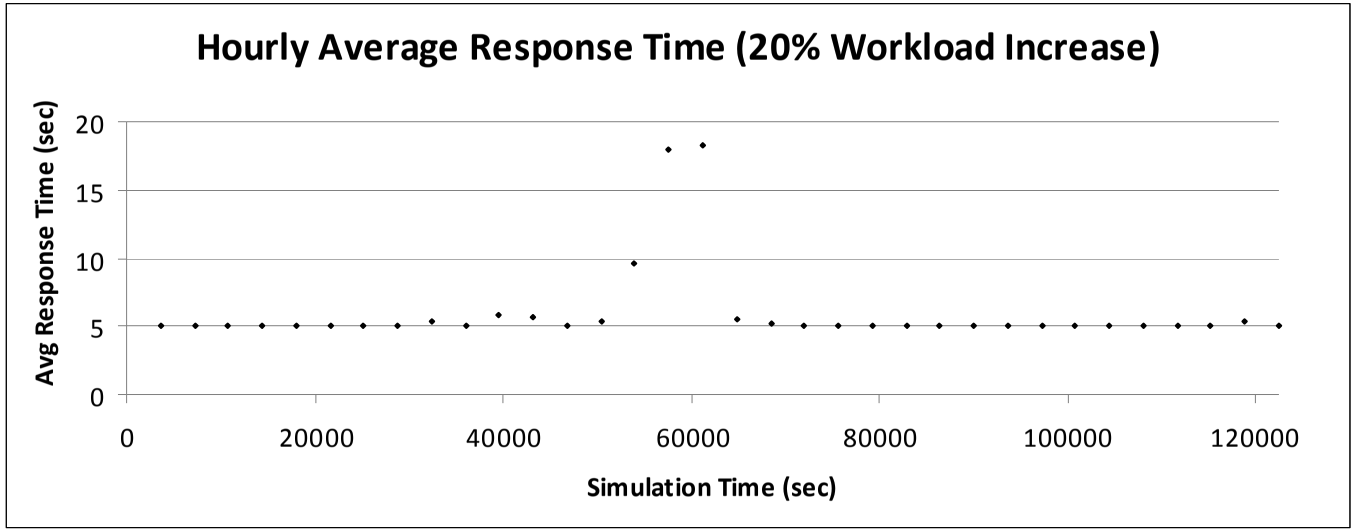

Hourly Response Time Coefficient of Variance (Current Workload)
CV (sec)
0.02
0.015
0.01
0.005
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

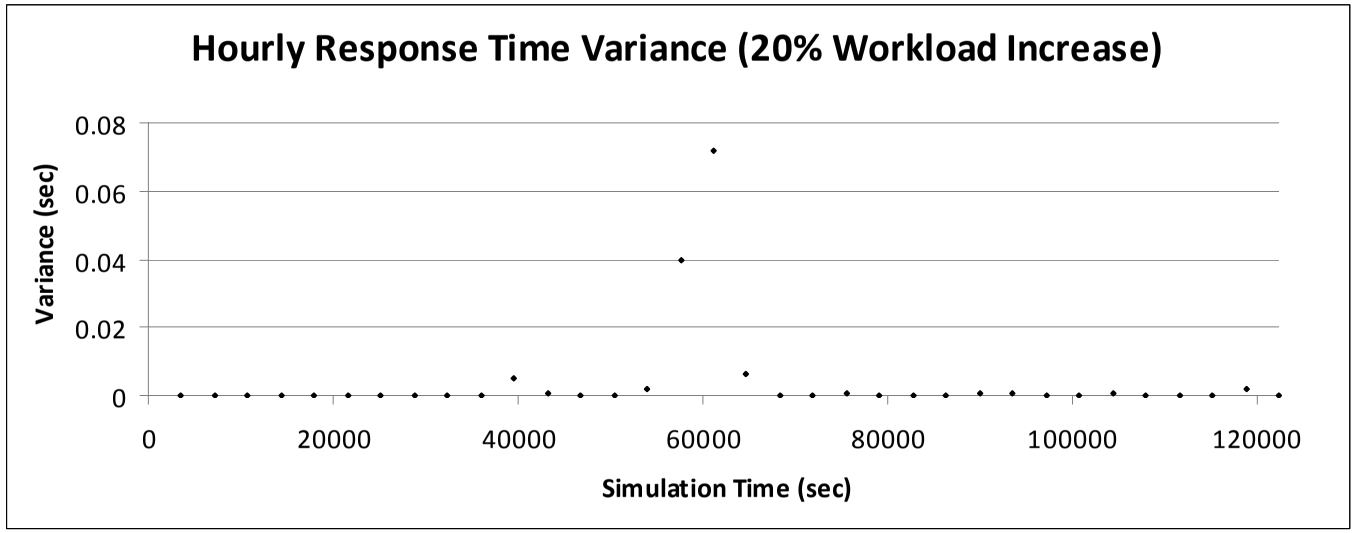

Hourly Average Response Time (10% Workload Increase)
Avg Response Time (sec)
14
12
10
8
6
4
2
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

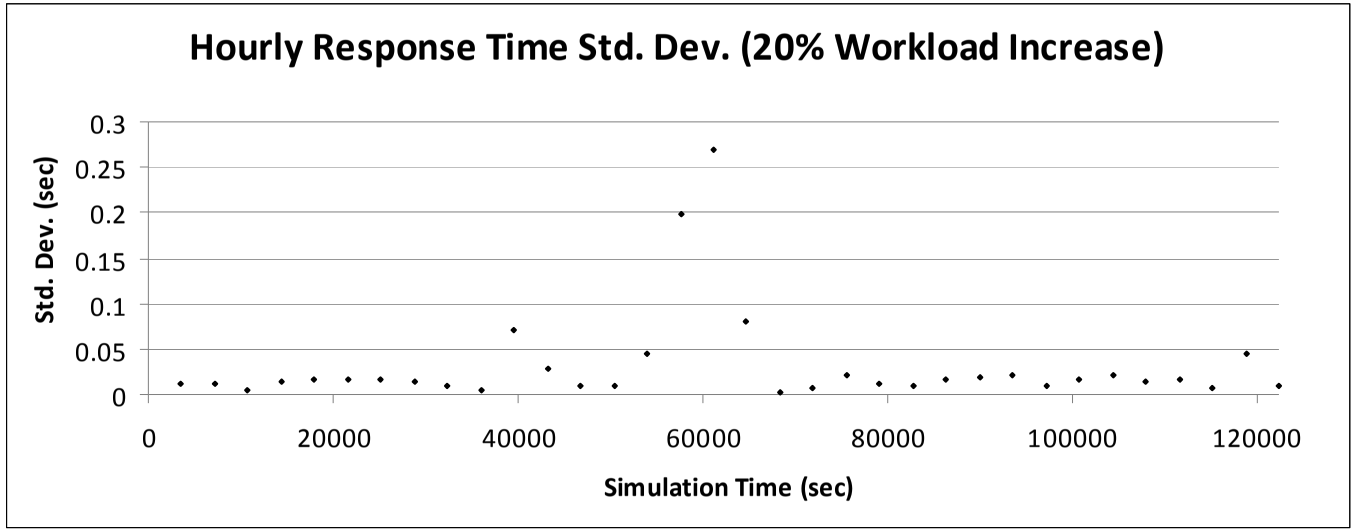

Hourly Response Time Variance (10% Workload Increase)
Variance (sec)
0.012
0.01
0.008
0.006
0.004
0.002
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

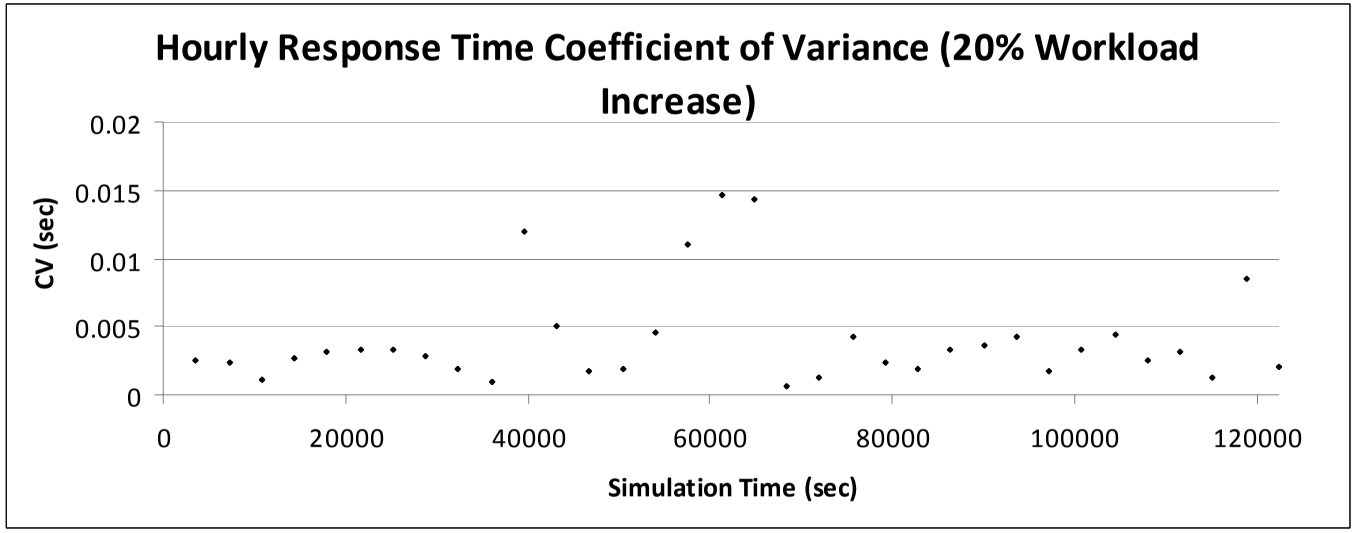

Hourly Response Time Std. Dev. (10% Workload Increase)
Std. Dev. (sec)
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

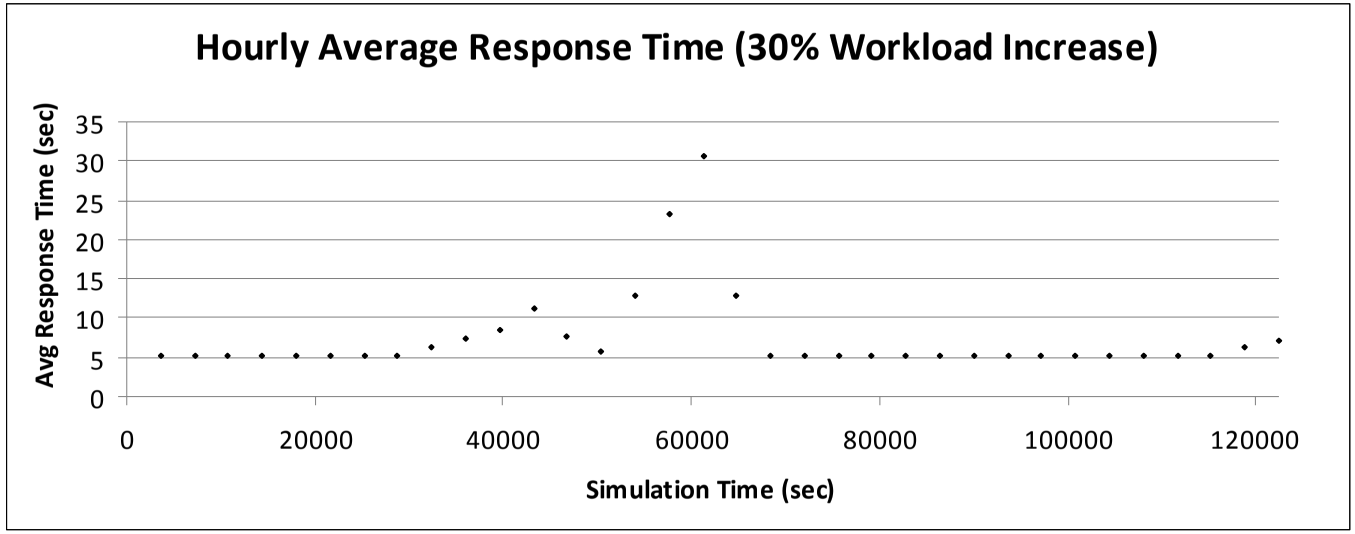

Hourly Response Time Coefficient of Variance (10% Workload Increase)
CV (sec)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

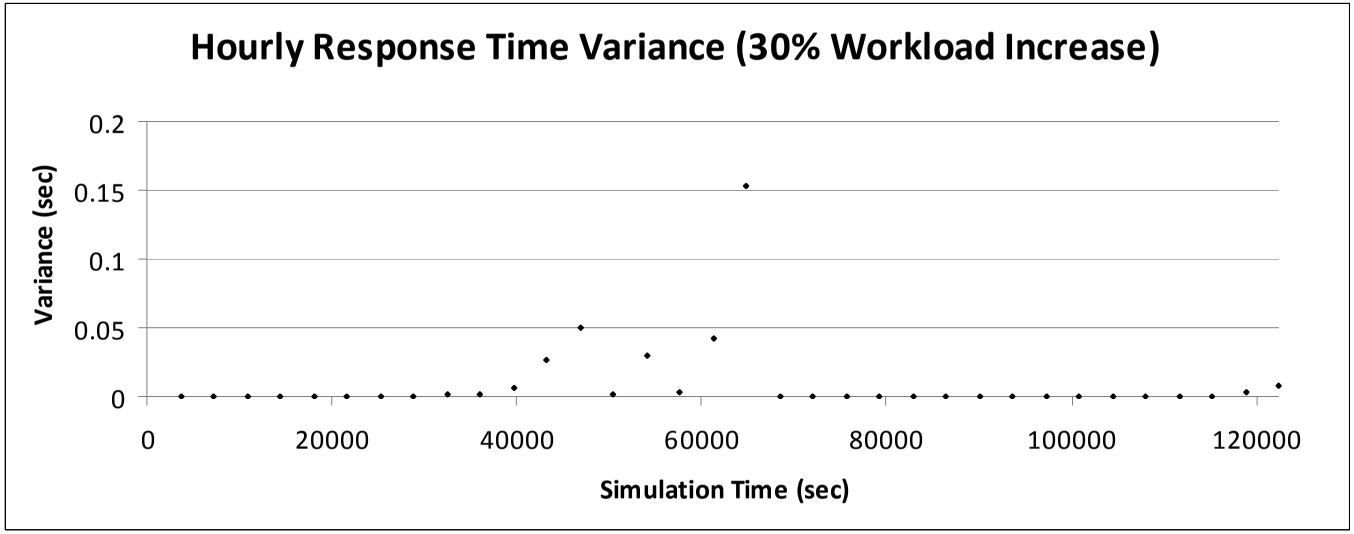

Hourly Average Response Time (20% Workload Increase)
Avg Response Time (sec)
20
15
10
5
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

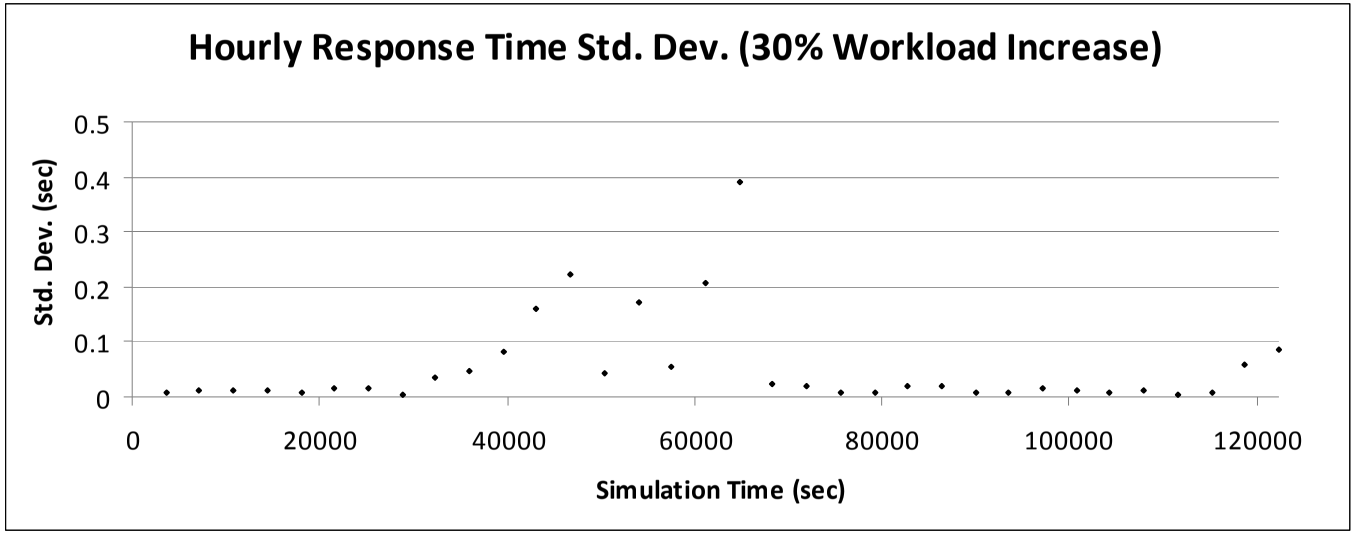

Hourly Response Time Variance (20% Workload Increase)
Variance (sec)
0.08
0.06
0.04
0.02
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

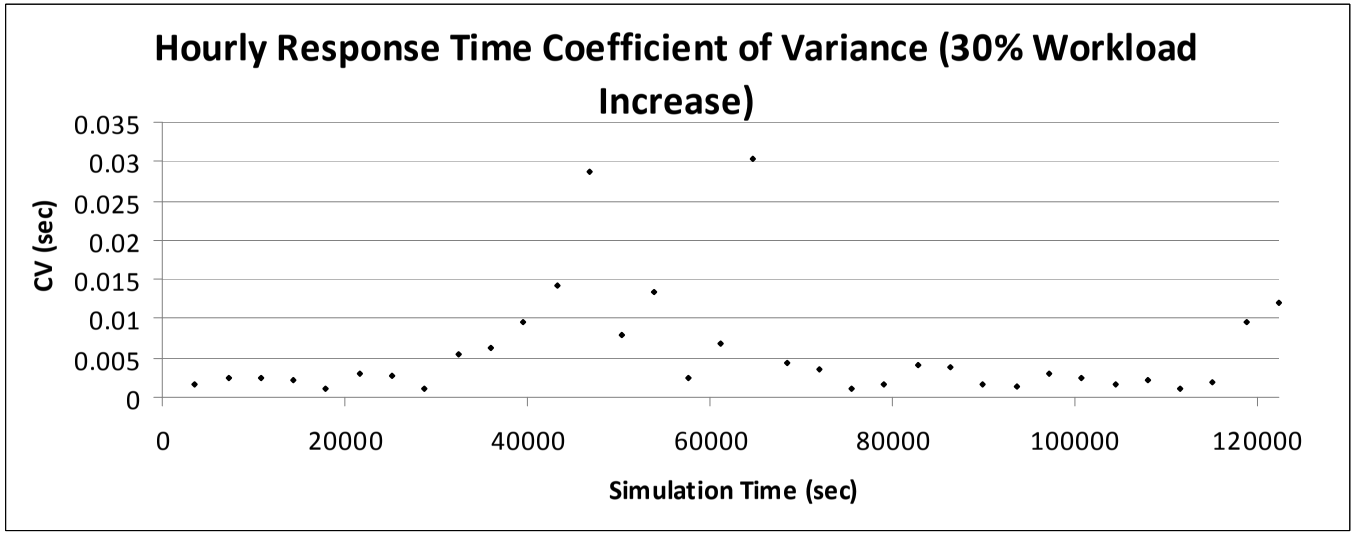

Hourly Response Time Std. Dev. (20% Workload Increase)
Std. Dev. (sec)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)


Hourly Response Time Coefficient of Variance (20% Workload Increase)
CV (sec)
0.02
0.015
0.01
0.005
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

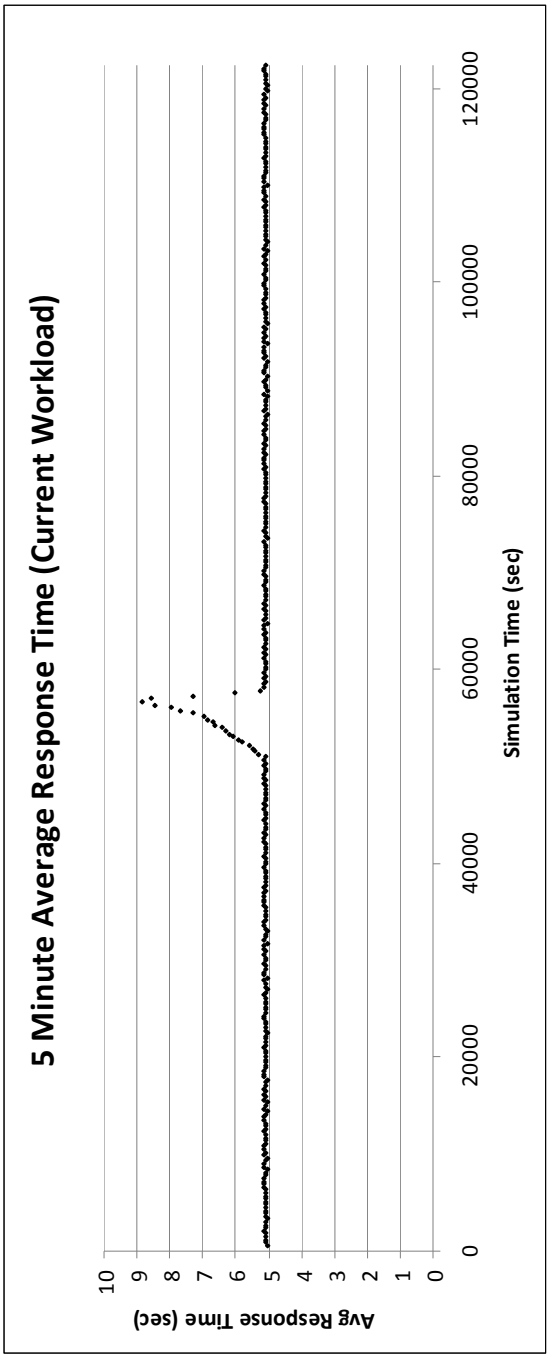

Hourly Average Response Time (30% Workload Increase)
Avg Response Time (sec)
35
30
25
20
15
10
5
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

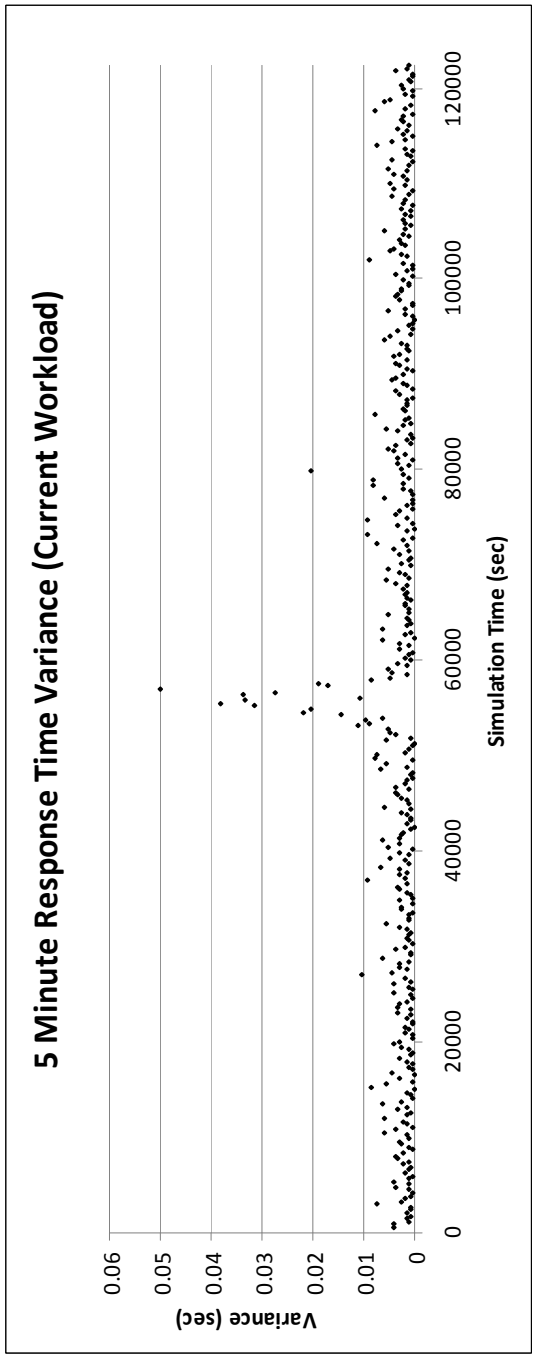

Hourly Response Time Variance (30% Workload Increase)
Variance (sec)
0.2
0.15
0.1
0.05
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

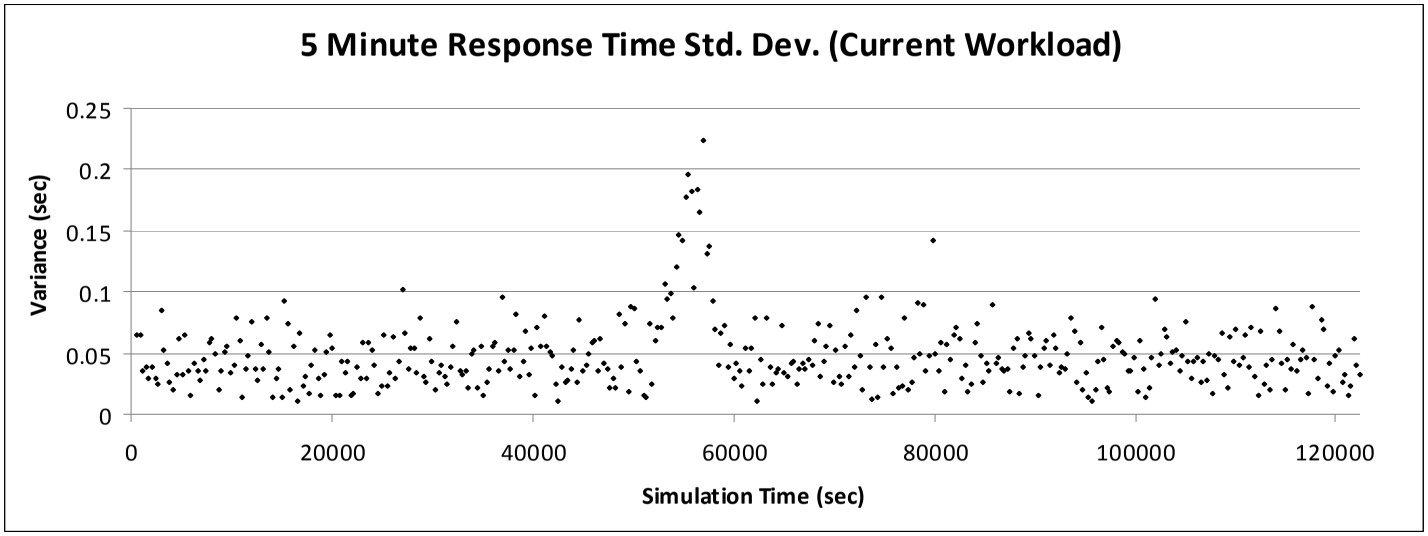

Hourly Response Time Std. Dev. (30% Workload Increase)
Std. Dev. (sec)
0.5
0.4
0.3
0.2
0.1
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

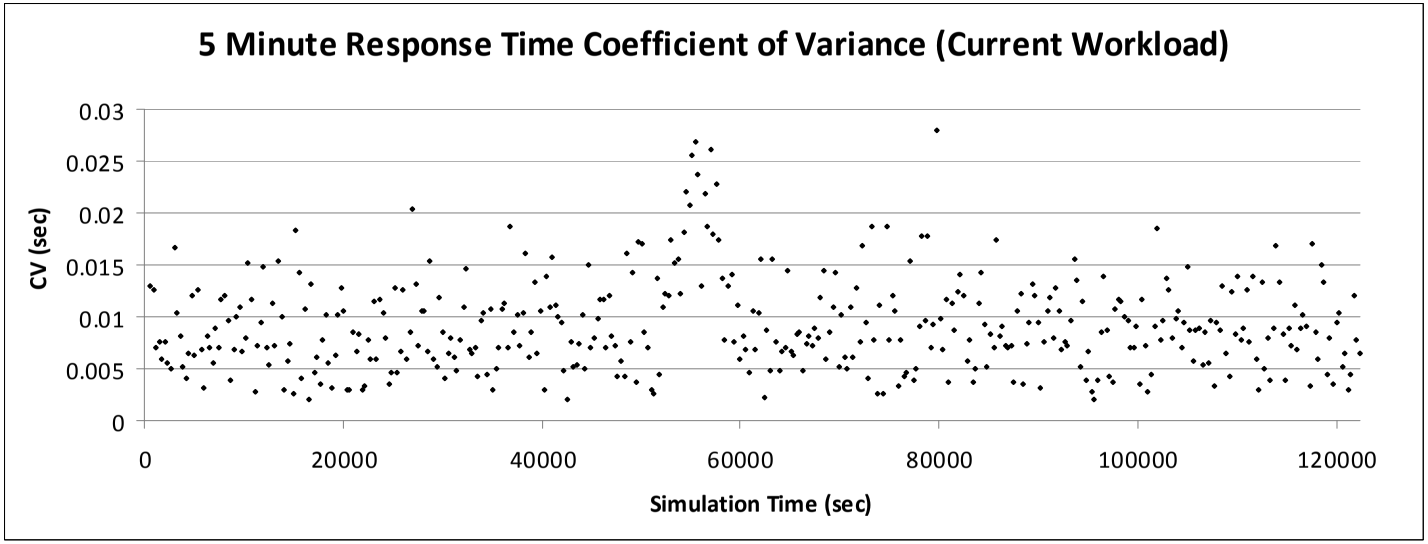

Hourly Response Time Coefficient of Variance (30% Workload Increase)
CV (sec)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

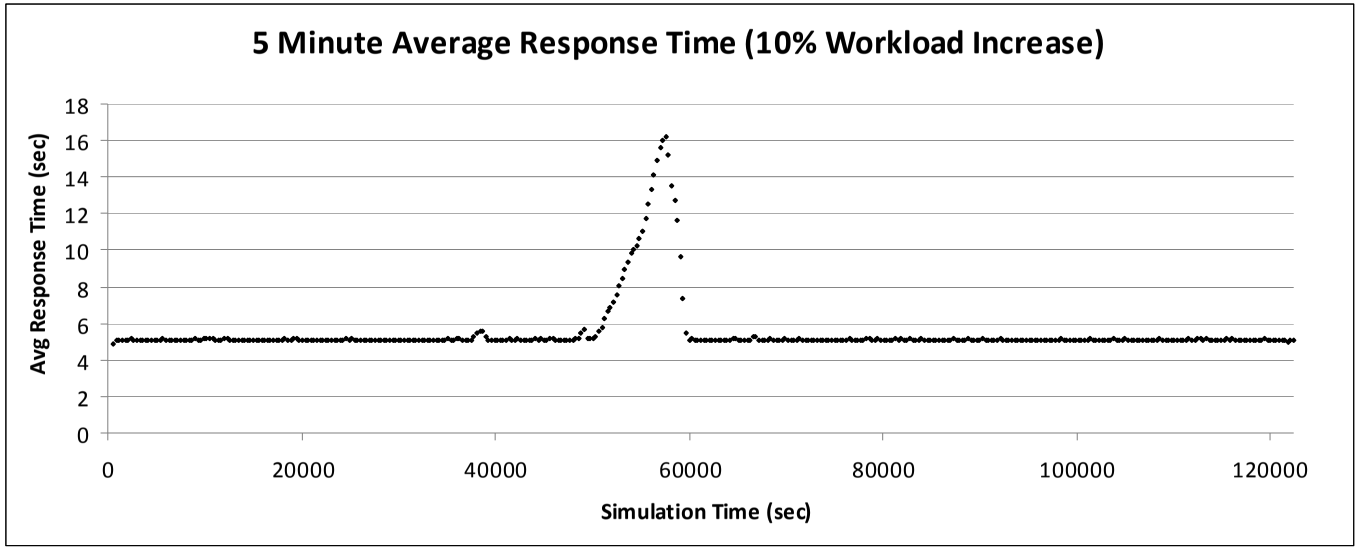
Appendix I: Five Minute Average Response Time Charts

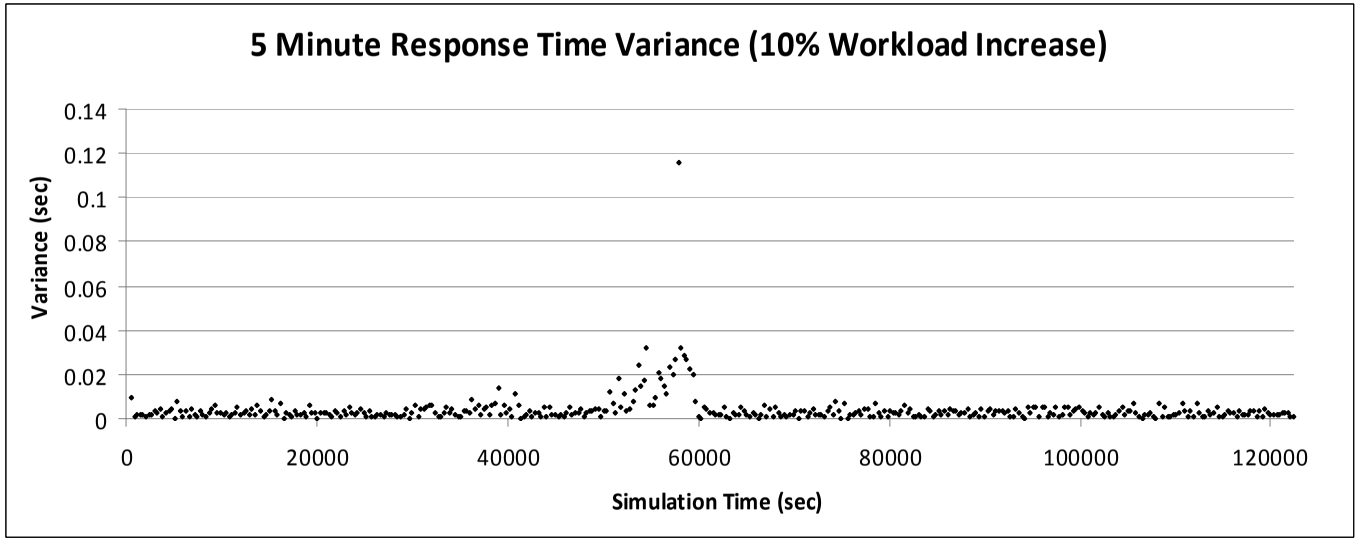


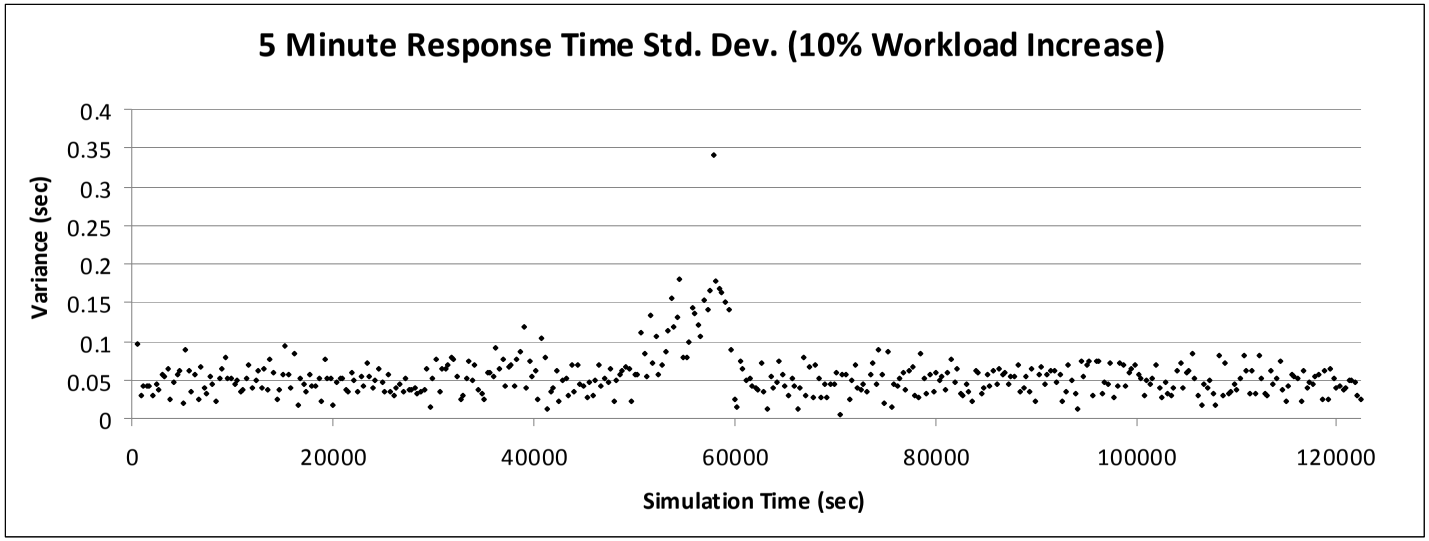


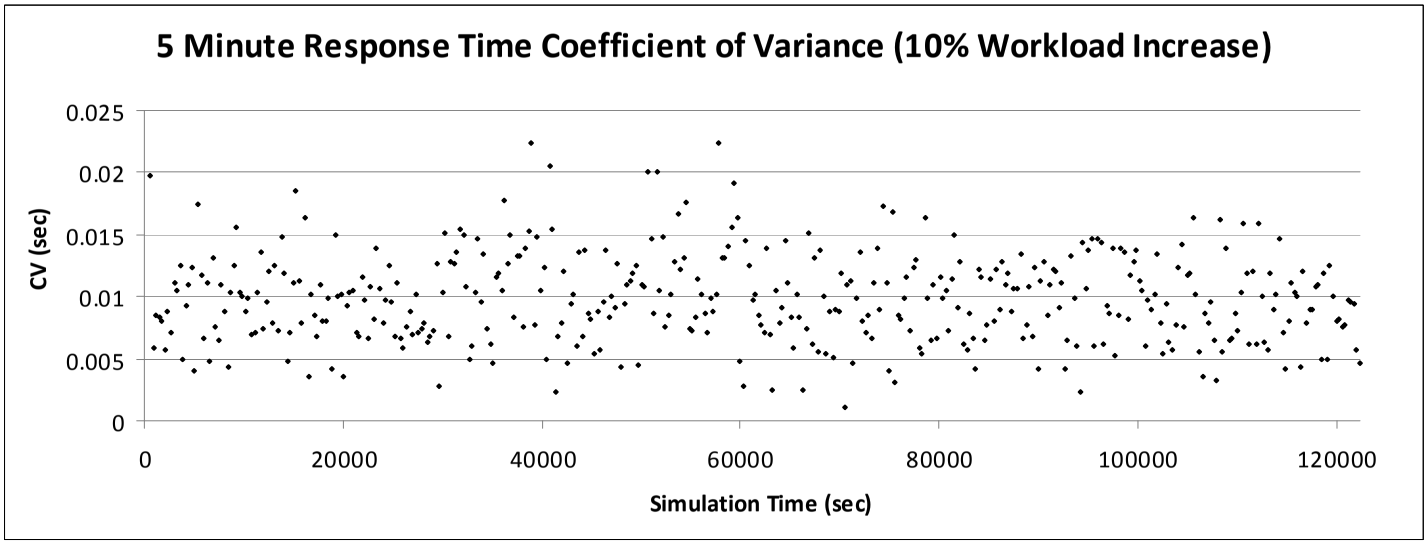

5 Minute Response Time Std. Dev. (Current Workload)
Variance (sec)
0.25
0.2
0.15
0.1
0.05
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

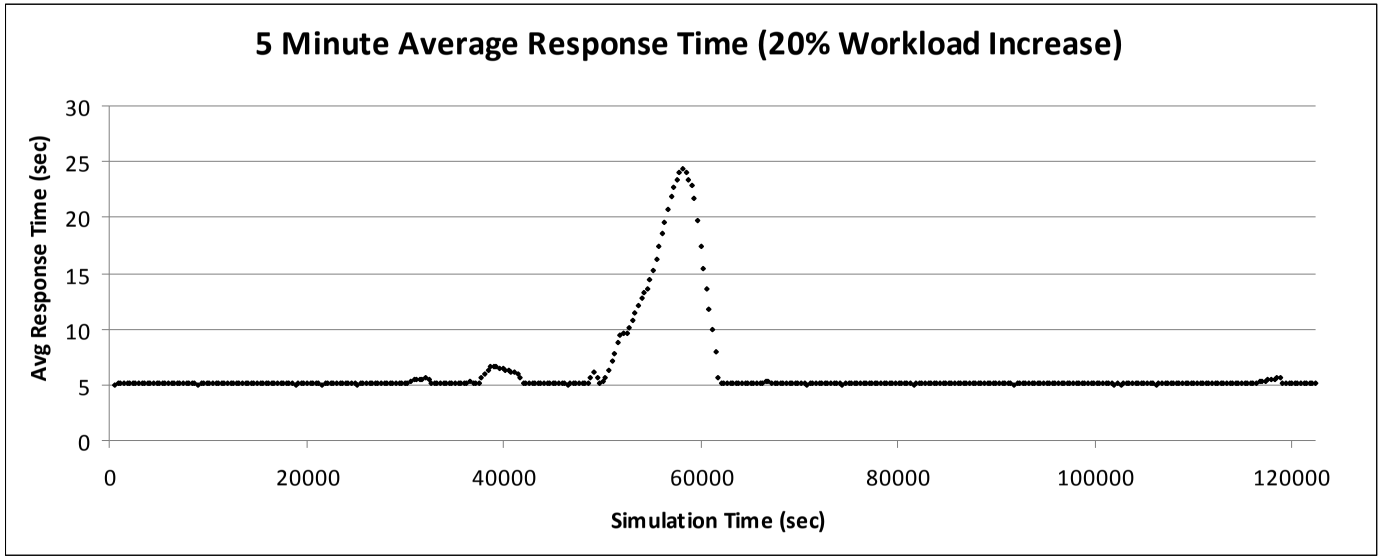

5 Minute Response Time Coefficient of Variance (Current Workload)
CV (sec)
0.03
0.025
0.02
0.015
0.01
0.005
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

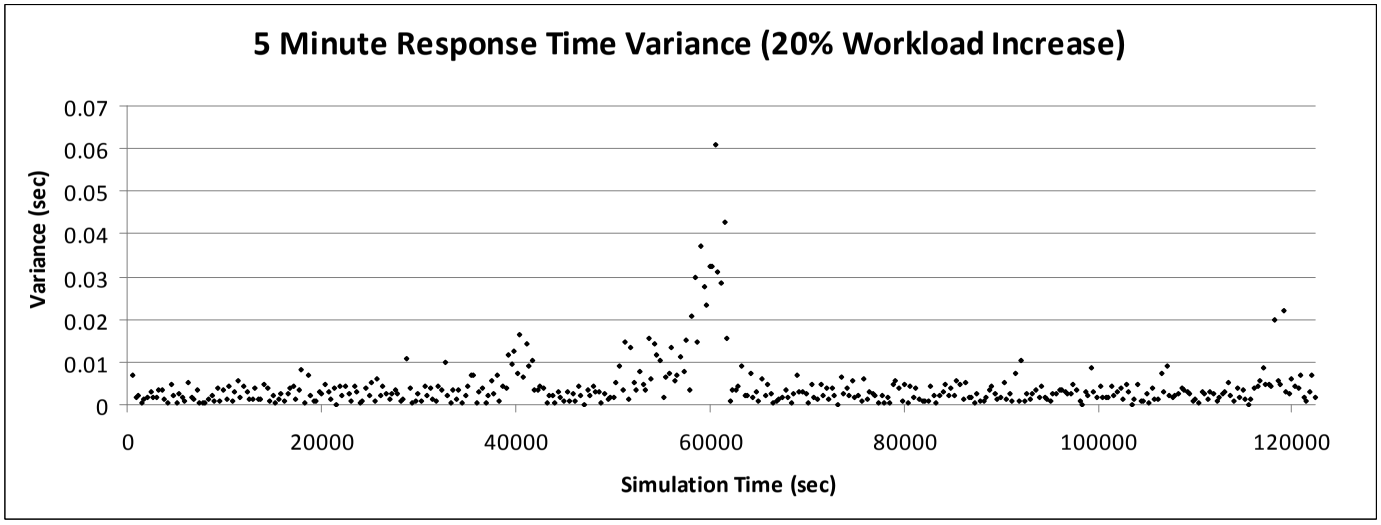

5 Minute Average Response Time (10% Workload Increase)
Avg Response Time (sec)
18
16
14
12
10
8
6
4
2
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

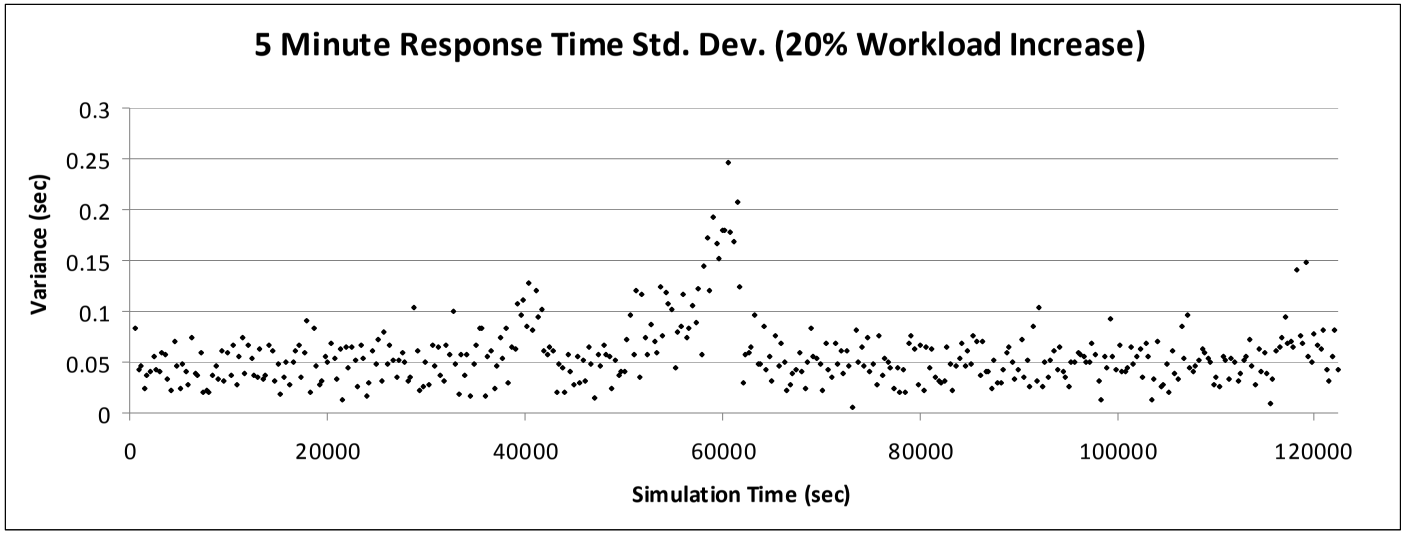

5 Minute Response Time Variance (10% Workload Increase)
Variance (sec)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

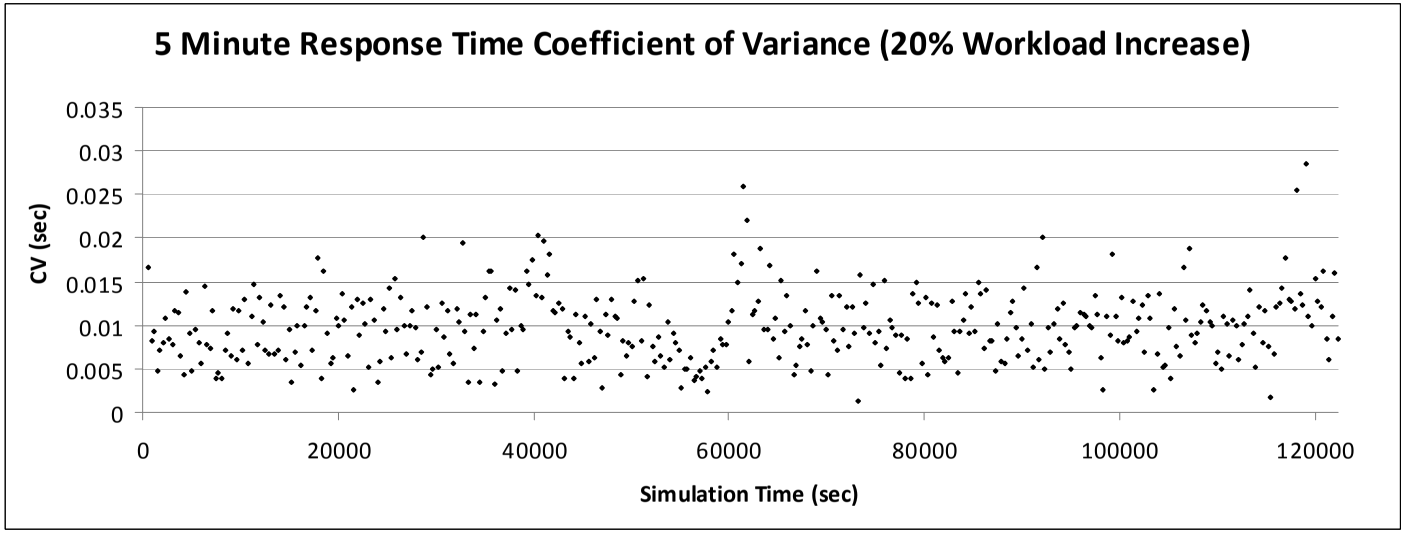

5 Minute Response Time Std. Dev. (10% Workload Increase)
Variance (sec)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

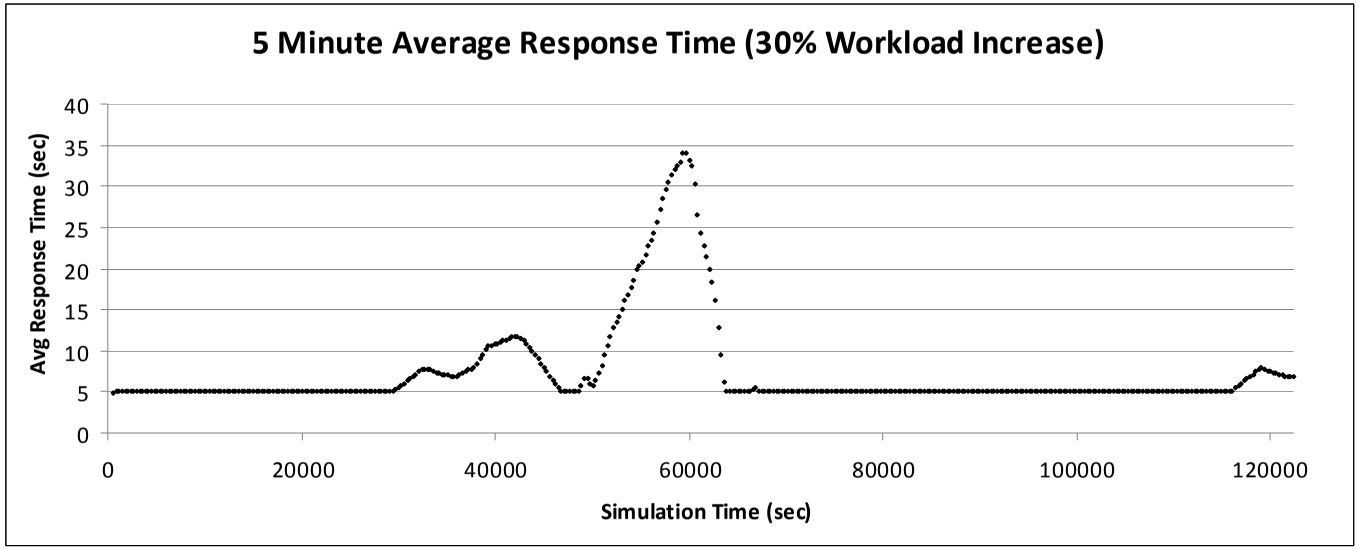

5 Minute Response Time Coefficient of Variance (10% Workload Increase)
CV (sec)
0.025
0.02
0.015
0.01
0.005
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

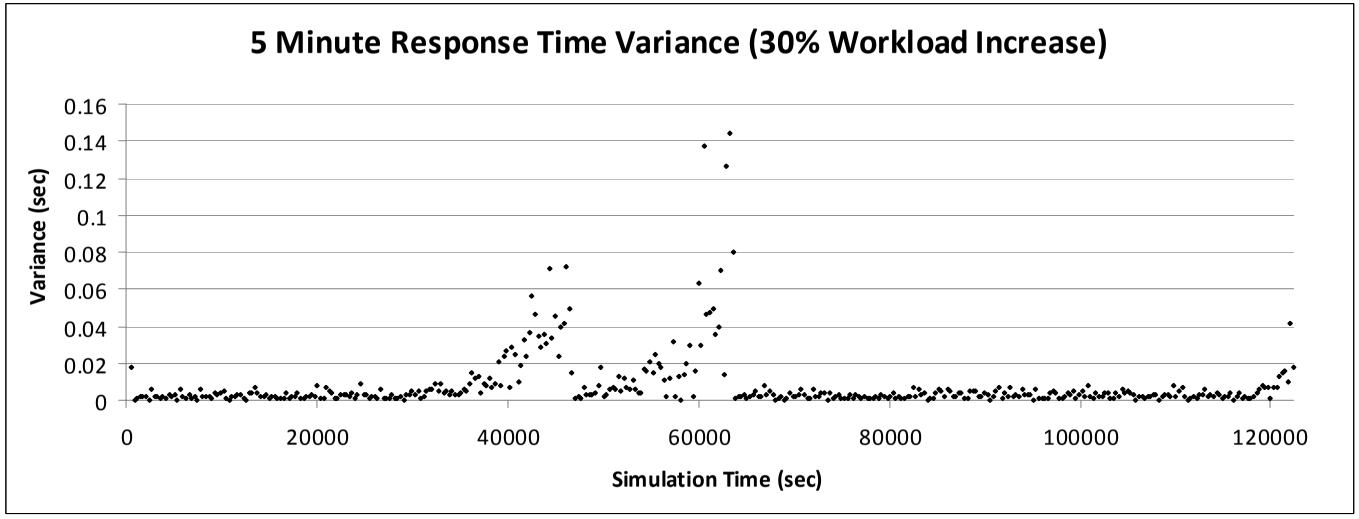

5 Minute Average Response Time (20% Workload Increase)
Avg Response Time (sec)
30
25
20
15
10
5
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

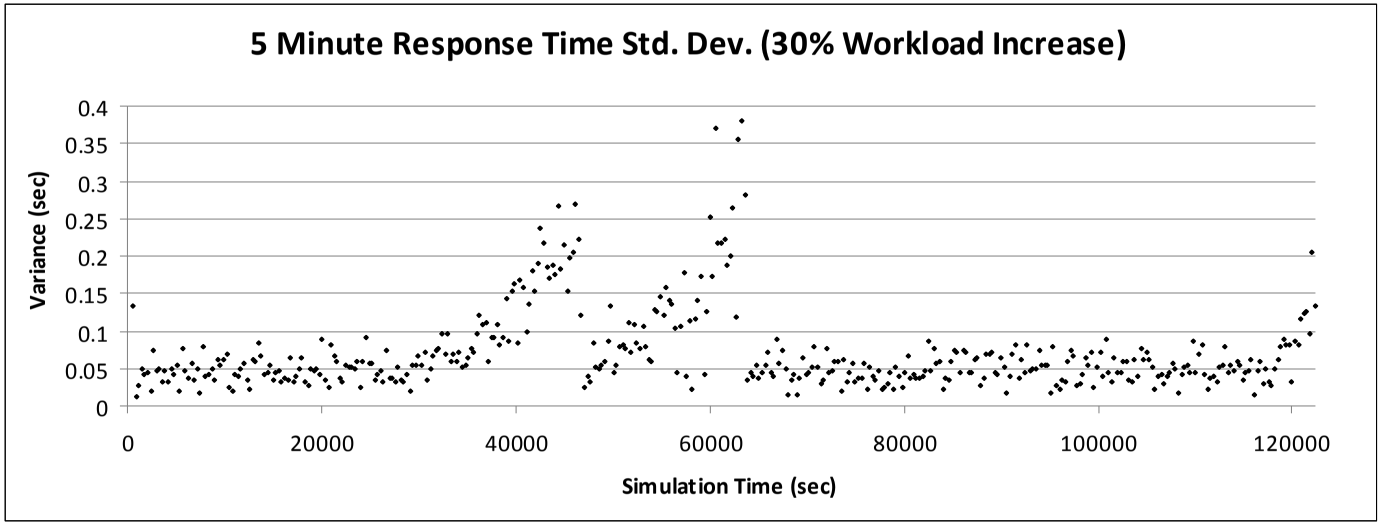

5 Minute Response Time Variance (20% Workload Increase)
Variance (sec)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

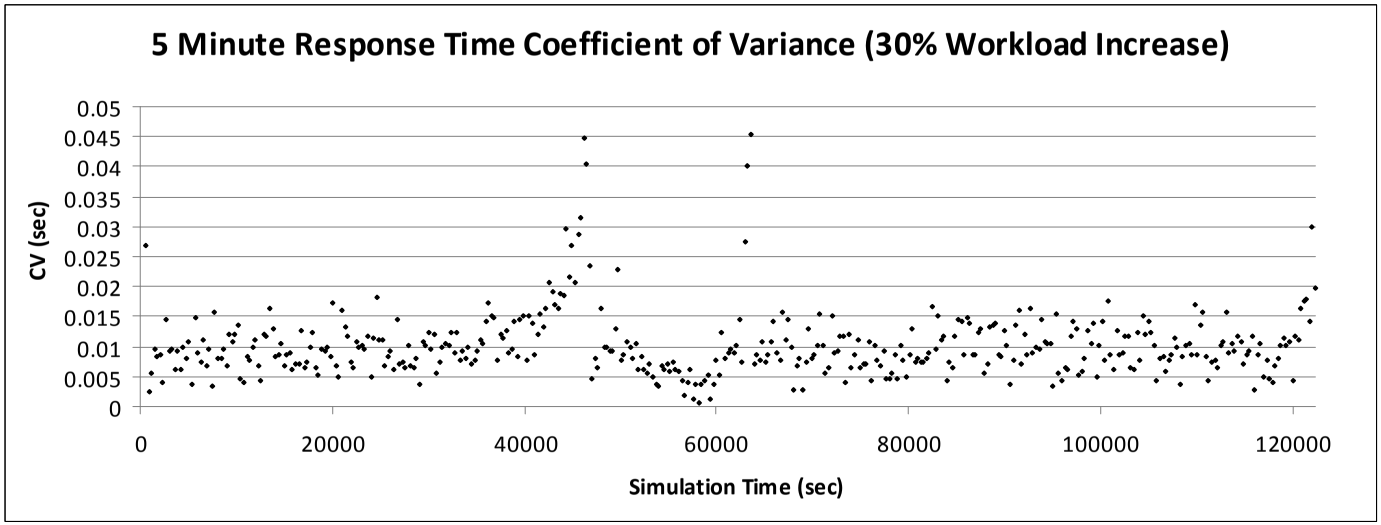

5 Minute Response Time Std. Dev. (20% Workload Increase)
Variance (sec)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)


5 Minute Response Time Coefficient of Variance (20% Workload Increase)
CV (sec)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

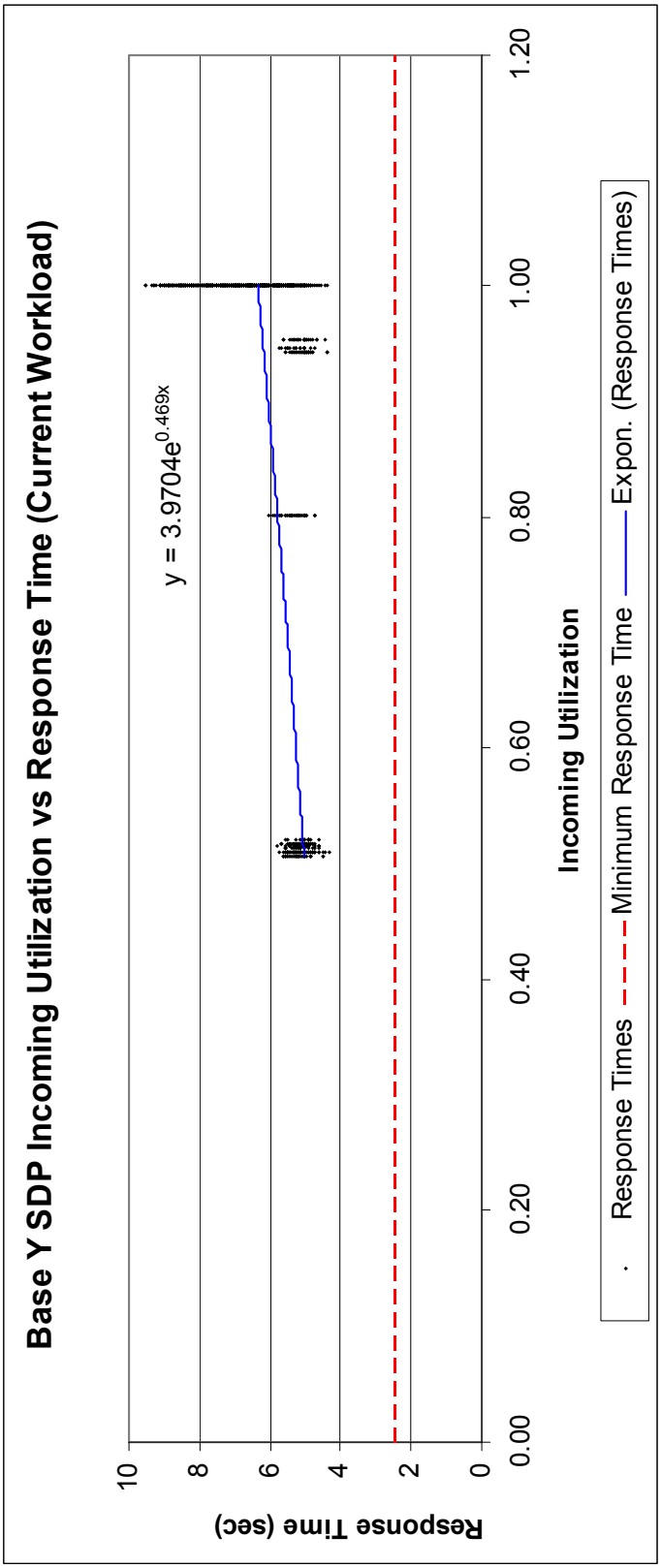

5 Minute Average Response Time (30% Workload Increase)
Avg Response Time (sec)
40
35
30
25
20
15
10
5
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

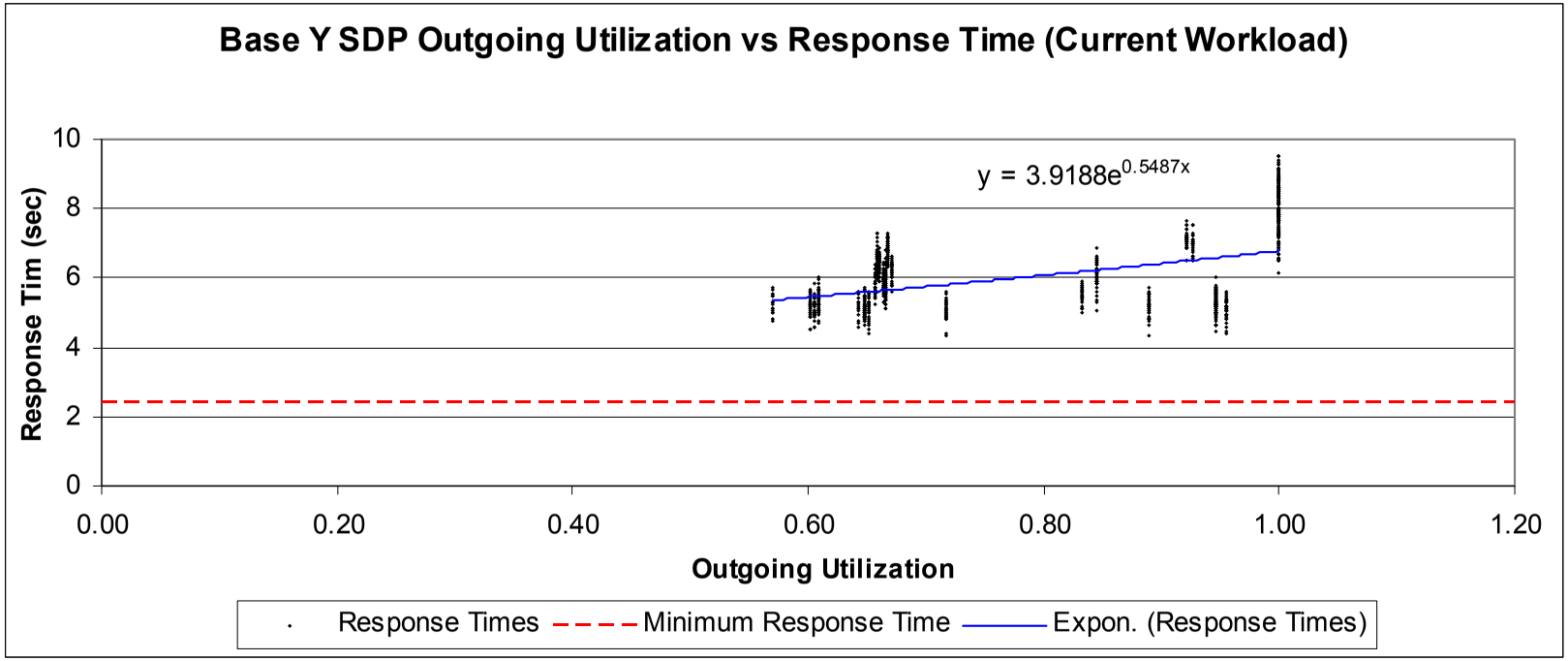

5 Minute Response Time Variance (30% Workload Increase)
Variance (sec)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

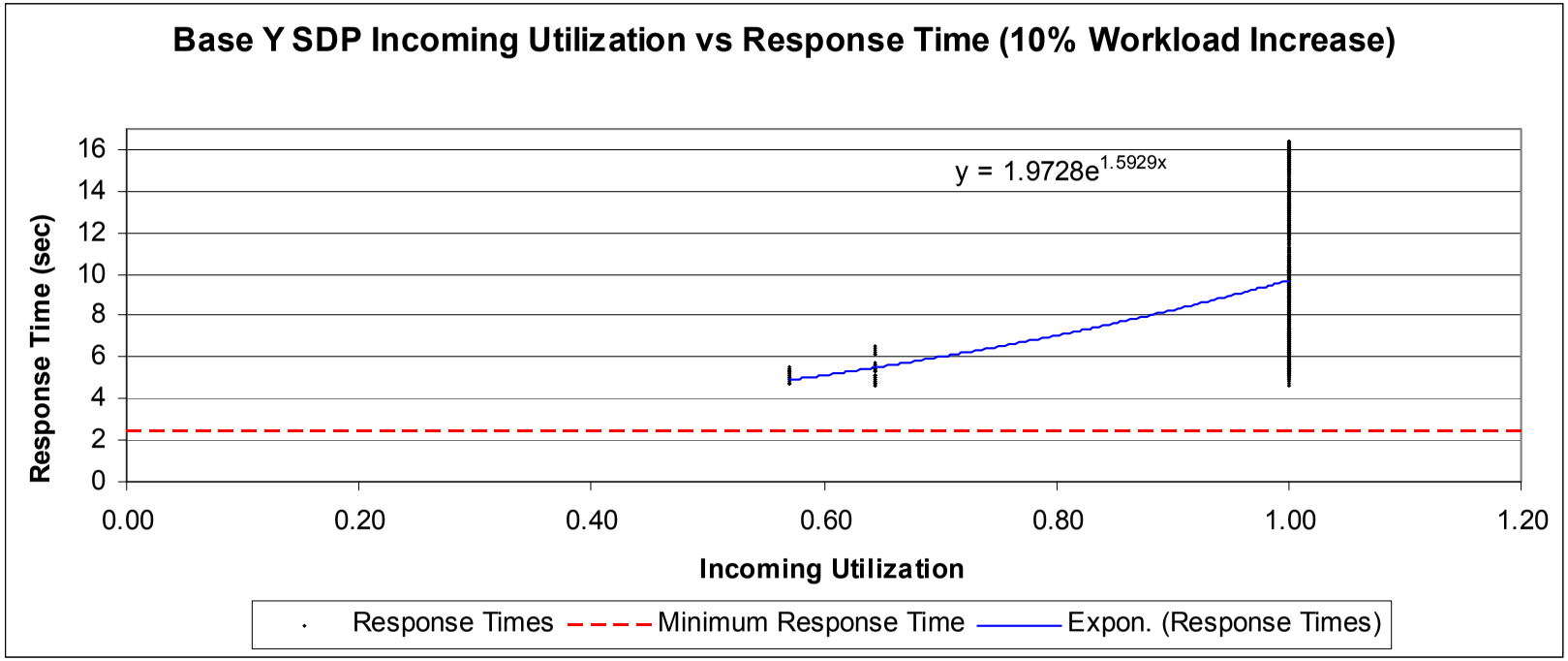

5 Minute Response Time Std. Dev. (30% Workload Increase)
Variance (sec)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

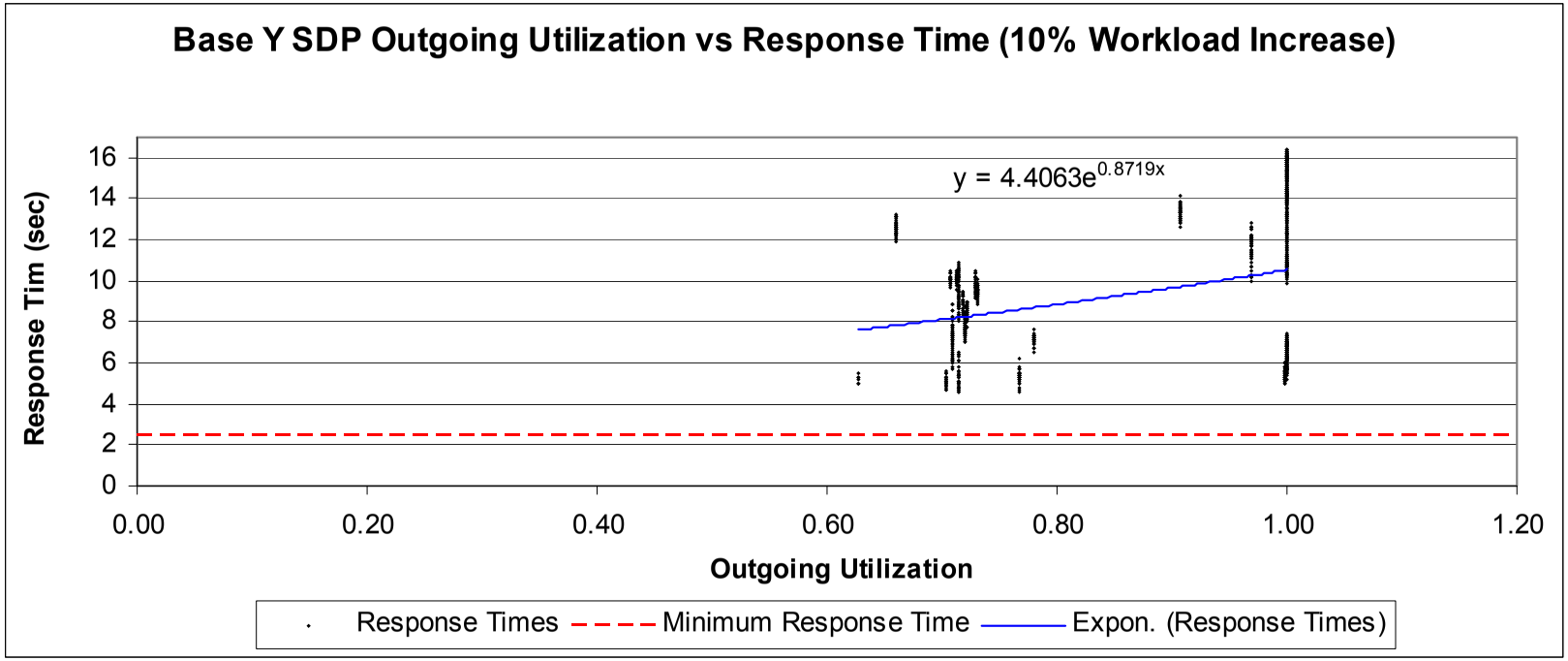

5 Minute Response Time Coefficient of Variance (30% Workload Increase)
CV (sec)
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
20000
40000
60000
80000
100000
120000
Simulation Time (sec)

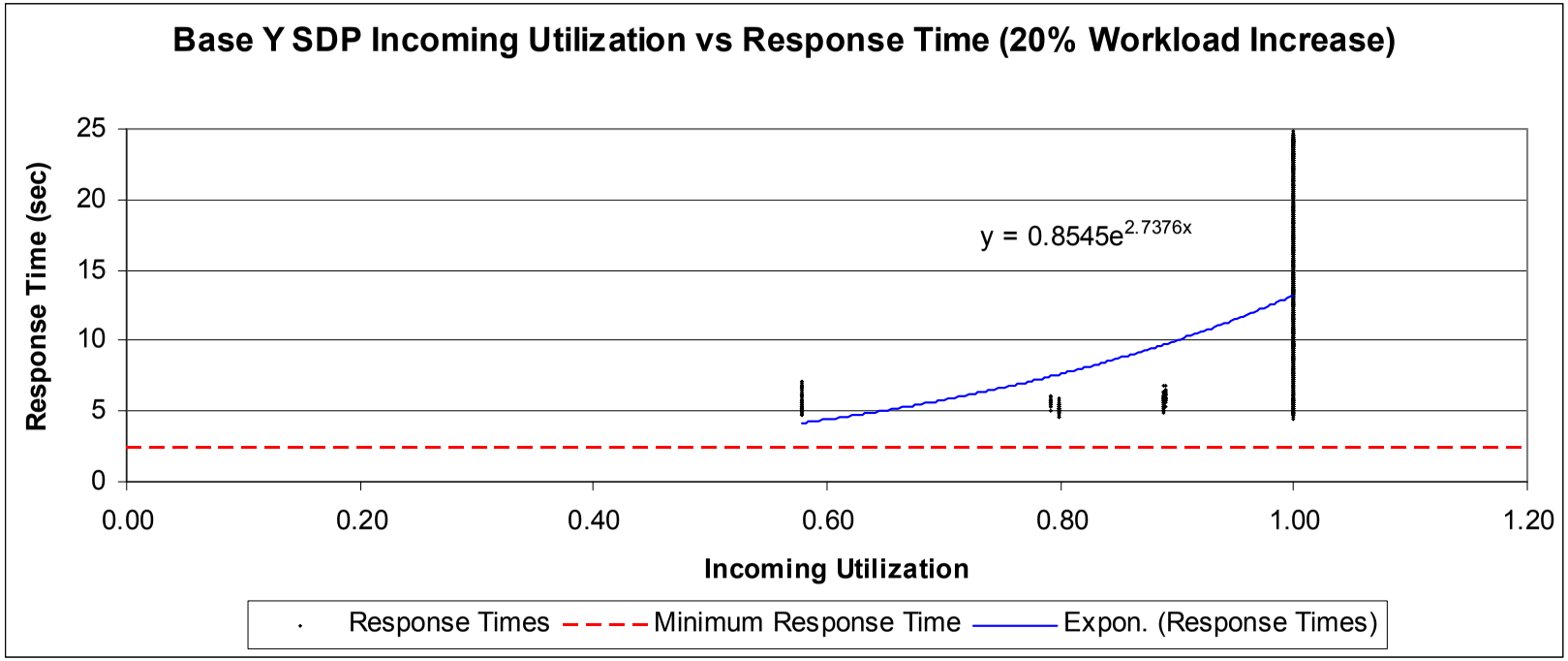
Appendix J: Utilization vs. Response Time Charts

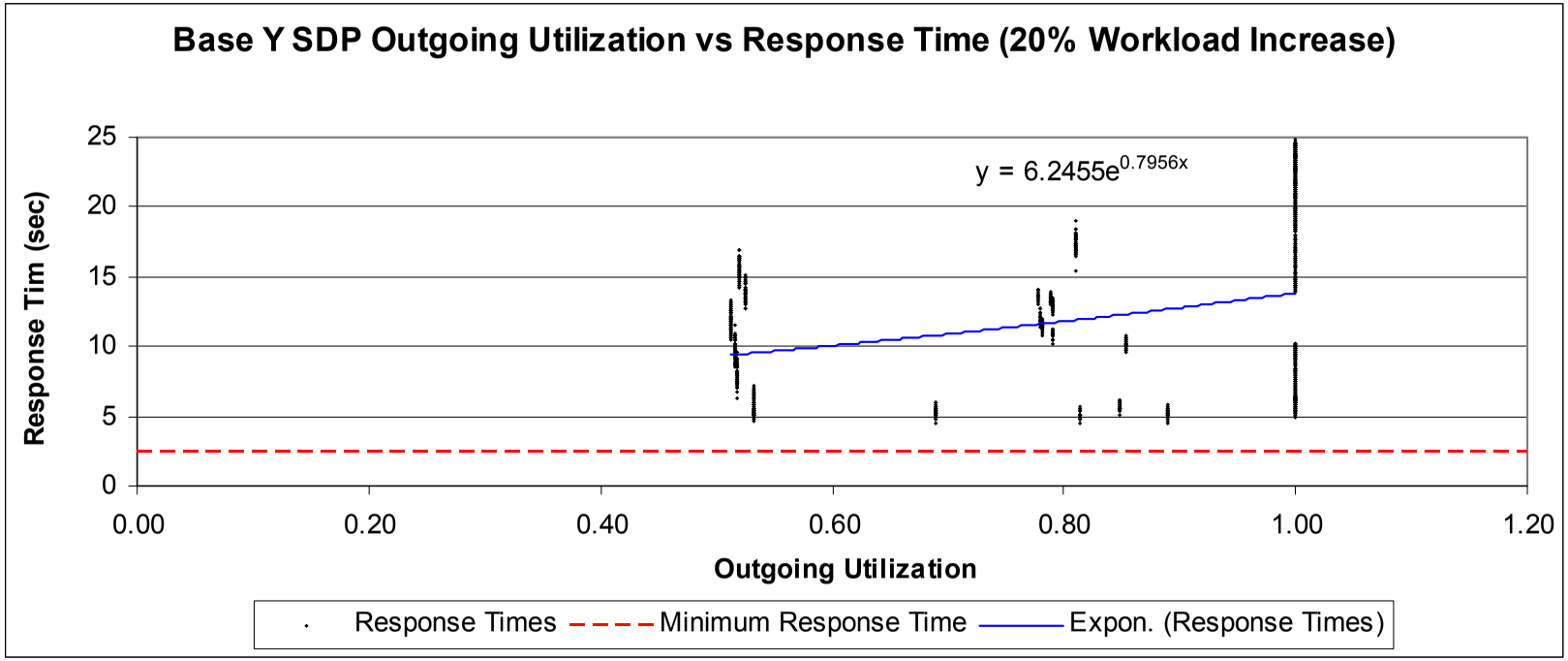


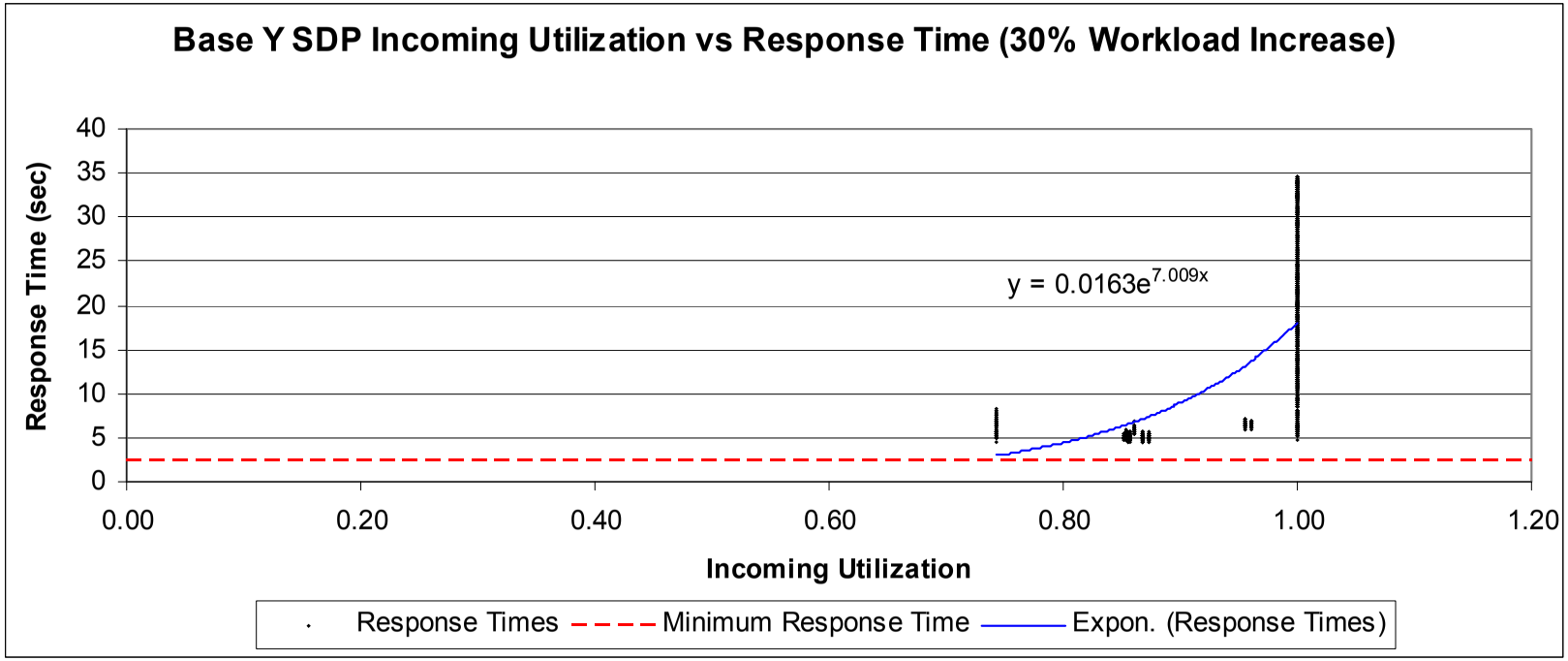

Base Y SDP Outgoing Utilization vs Response Time (Current Workload)
y = 3.9188e^0.5487x
Response Tim (sec)
10
8
6
4
2
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Outgoing Utilization
Response Times
Minimum Response Time
Expon. (Response Times)

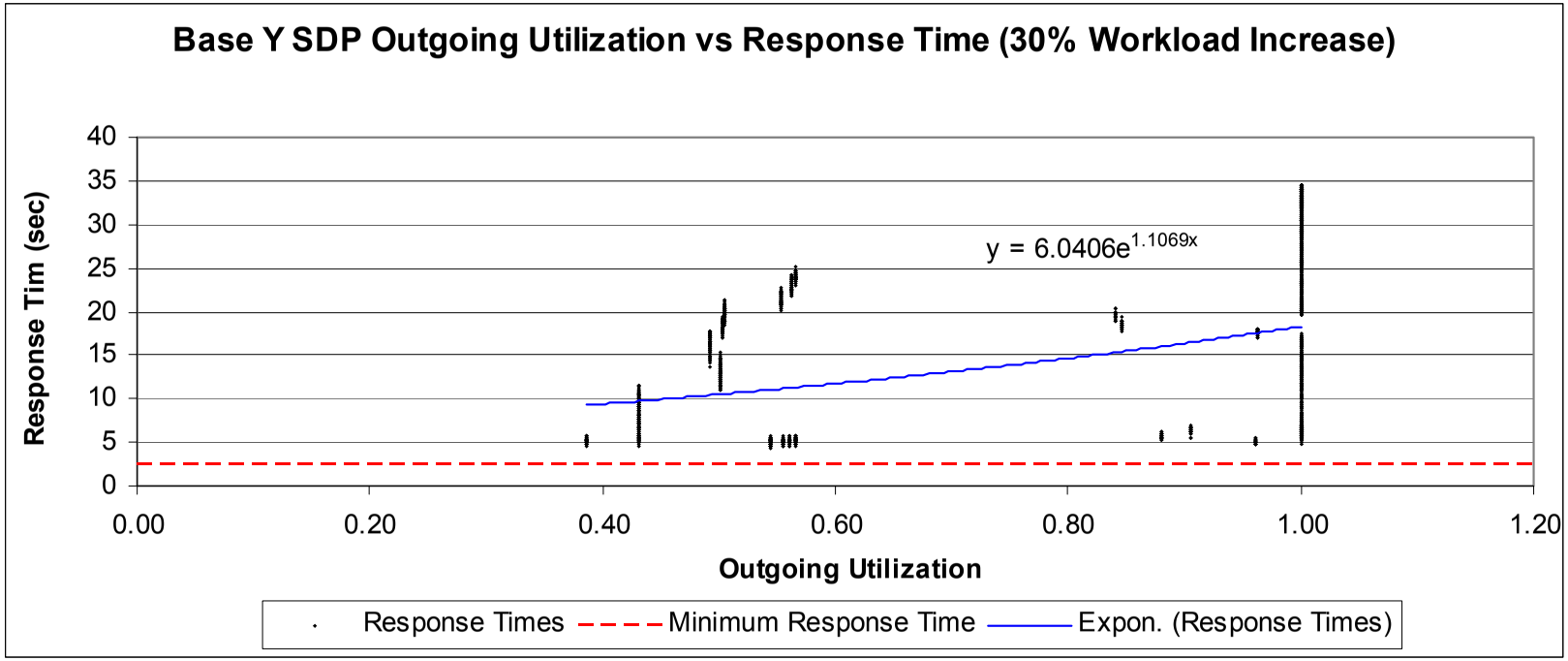

Base Y SDP Incoming Utilization vs Response Time (10% Workload Increase)
y = 1.9728e^1.5929x
Response Time (sec)
16
14
12
10
8
6
4
2
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Incoming Utilization
Response Times
Minimum Response Time
Expon. (Response Times)


Base Y SDP Outgoing Utilization vs Response Time (10% Workload Increase)
y = 4.4063e^0.8719x
Response Tim (sec)
16
14
12
10
8
6
4
2
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Outgoing Utilization
Response Times
Minimum Response Time
Expon. (Response Times)


Base Y SDP Incoming Utilization vs Response Time (20% Workload Increase)
Response Time (sec)
25
20
15
10
5
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Incoming Utilization
y = 0.8545e2.7376x
Response Times
Minimum Response Time
Expon. (Response Times)


Base Y SDP Outgoing Utilization vs Response Time (20% Workload Increase)
Response Tim (sec)
25
20
15
10
5
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Outgoing Utilization
y = 6.2455e^0.7956x
Response Times
Minimum Response Time
Expon. (Response Times)


Base Y SDP Incoming Utilization vs Response Time (30% Workload Increase)
Response Time (sec)
40
35
30
25
20
15
10
5
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Incoming Utilization
y = 0.0163e^7.009x
Response Times
Minimum Response Time
Expon. (Response Times)


Base Y SDP Outgoing Utilization vs Response Time (30% Workload Increase)
Response Tim (sec)
40
35
30
25
20
15
10
5
0
y = 6.0406e^1.1069x
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Outgoing Utilization
Response Times
Minimum Response Time
Expon. (Response Times)

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