Decision Making in the HIV/AIDS Supply Chain

by

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Bachelors of Science, Industrial Engineering
Northwestern University, 2003

Submitted to the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degree of

MASTER OF ENGINEERING IN LOGISTICS

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2007

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Abstract

During the first two decades of HIV/AIDS awareness, the U.S. and foreign governments responded slowly to the crisis. In contrast today, as the pandemic continues, initiatives of nonprofit organizations have dramatically increased the amount of available funding. Countries must work to effectively allocate the influx of resources. This paper examines one area for improvement within the context of the developing world: supply chain management. The HIV/AIDS supply chain in a resource-poor setting differs from traditional networks. In order to properly manage operational activities, it is important to understand inherent system complexities, such as bureaucratic funding, forced ordering, shrinkage, and human capital constraints. This research explores these issues and identifies five scenarios that impact performance measures. The model, developed through an integrated supply chain approach, simulates the effects of scenarios on inventory level, cycle service level, and missed treatment dosages. Supply chain planning without accounting for system complexities leads to significant drops in service performance from theoretical expectations. Countries should order excess inventory to compensate for these issues. Funding efforts should focus on training resources to properly manage treatment demand and target operational changes that yield the highest improvements on performance metrics. Short-run and long-run tactics must be aligned to avoid the threat of widespread resistance, which results from inconsistent treatment and poor patient care. The goal of this research is to understand the HIV/AIDS supply chain and identify the best areas for resource investment.

Acknowledgment

This thesis would not have been possible without the valuable guidance of my thesis advisor, Dr. Edgar Blanco of MIT, and insights from individuals at the Clinton Foundation, USAID, Center for Disease Control, and Institute of Healthcare Improvement. I would also like to thank Dr. Chris Caplice, Director of MLOG, for helping me make the most out of my academic experience. I am continually grateful for the support of my family and friends, and encouragement from my fellow MLOG classmates.

Biographical Note

Elaine Cao completed a Bachelor of Science in Industrial Engineering at Northwestern University. She graduated with departmental honors, a minor in Economics, and a certificate in Applied Mathematics. After graduating, she worked as a consultant in Accenture's Health & Life Science practice and Huron's Performance Improvement group. In 2006 she left to attend MIT where her focus has been on healthcare process improvement.

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1 Introduction

The prevalence of HIV/AIDS increases year after year in poverty stricken nations. In order for these countries to establish a stable economy, work must be done to combat the spread of disease. The need to effectively allocate financial resources escalates as the efforts of nonprofit organizations continue. This research explores one area for improvement, supply chain management. HIV/AIDS treatment in developing countries is particularly interesting because of the distinct nature of the drug and the resource constrained environment in which it is administered. The three main objectives are to:

- Understand the major obstacles in managing an efficient HIV/AIDS supply chain
- Identify the economic impacts of inadequate patient care due to a poorly managed system
- Develop a high-level model that will help nonprofit organizations assess their current operations and make effective future decisions

For a variety of reasons, the nonprofit HIV/AIDS supply chain, particularly in poor countries, differs from traditional supply chains. This paper explores these differences and analyzes methods for better management control. The constructed research model tracks drug inventory and cycle service levels in an integrated upstream and downstream approach while accounting for operational issues.

Research Question: *How can developing countries most effectively manage their supply chain given the complexities of the environment?*

1.1 Motivation

A significant unmet need for HIV/AIDS treatment and mounting funds motivates this academic endeavor. An estimated 39.5 million people suffer worldwide from HIV. In 2006, 4.3 million new patients were diagnosed and 2.9 million people died of AIDS-related illnesses.

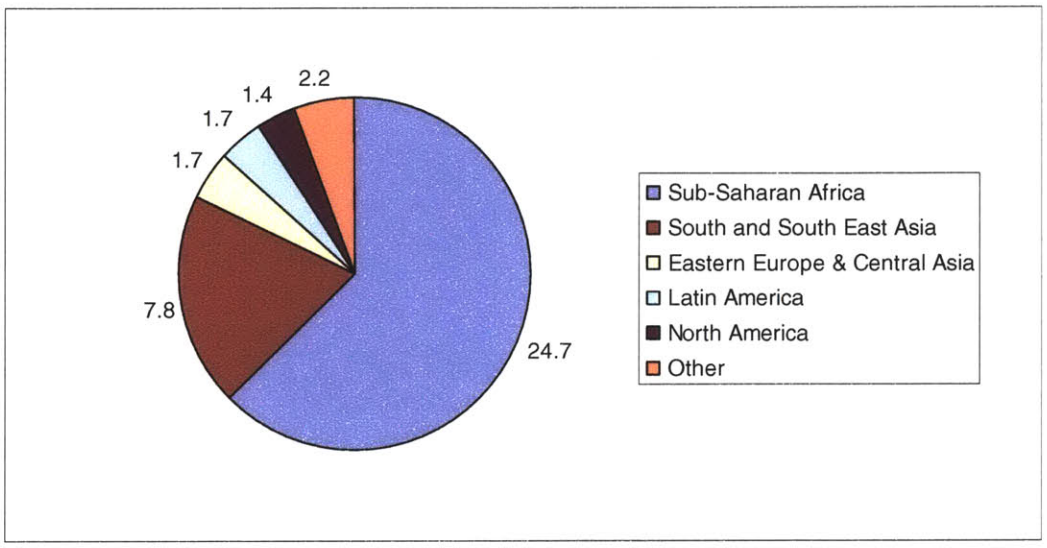

Figure 1: 2006 People Living with HIV (in millions)

Sub-Saharan Africa is the most affected region in the world with nearly 2/3 of the total disease population. Not all infected individuals require drug treatment. Physicians prescribe drugs based on disease symptoms, level of CD4 count [1], and viral load. According to UNAIDS, 6.5 million people require drug therapy, but only 1.3 million are treated. This equates to 80% of people living with HIV/AIDS receiving inadequate health care. See table 1 on the following page.

[1] The CD4 count indicates immune strength and disease stage advancement.

Table 1: Unmet HIV Treatment Demand (Dec. 2005)

Region	Est. No. of People Receiving Treatment (Dec. 2005)	Est. No. of People Needing Treatment (Dec. 2005)	Percentage Covered
Sub-Saharan Africa	810,000	4,700,000	17%
Latin America & Caribbean	315,000	465,000	68%
East, South & South East Asia	180,000	1,100,000	16%
Europe	21,000	160,000	13%
Middle & North Africa	4,000	75,000	5%
Total	**1,330,000**	**6.5 Million**	**20%**

Given these overwhelming figures, projects established by the United Nations (UN), United States, and the World Health Organization (WHO) have propelled the issue of HIV/AIDS forward. The UN set one of its eight millennium goals towards halting and reversing the spread of HIV/AIDS by 2015. The current Bush administration started the U.S. President's Emergency Plan for AIDS Relief (PEPFAR). PEPFAR is the largest international health initiative dedicated to a single disease. The goal is to disperse $15 billion dollars in funding over the next five years. Furthermore, the WHO launched its '3 by 5' initiative on December 1, 2005 with the intent of providing 3 million people with HIV treatment by 2015.

The purpose of this research is to help countries make effective supply chain decisions given available resources and inherent complexities. Initiatives of nonprofit organizations continue to provide more funding as the threat of this disease continues. Initially the U.S. and countries abroad responded slowly to the AIDS pandemic, primarily because of the negative stigma associated with the disease. Governments, in the first 20 years of public awareness, 1981 to 2001, made little effort to address HIV/AIDS. However in 2005, $8.3 billion was available for AIDS funding, which is more than five

times the financial backing in 2001. This figure is expected to rise to $8.9 billion in 2006 and $10 billion in 2007. The large discrepancy in treatment access and demand makes efficient fund allocation critical in the battle against HIV/AIDS.

1.2 Overview

This study seeks to understand how developing nations can effectively manage their HIV/AIDS supply chain despite the complexities of operating in a resource-constrained environment. Chapter 2 identifies key supply chain issues, chapter 3 depicts the current supply chain, and chapter 4 describes ongoing nonprofit efforts. Collectively these sections illustrate the difficulties of distributing and administering HIV medication in developing countries. Poor supply chain management leads to suboptimal patient care. Chapter 5 explores the economic impacts of inconsistent treatment. The threat of widespread treatment resistance makes high patient service levels important. Treating resistant patients is more costly and will greatly hinder long-term efforts in combating HIV/AIDS. Chapter 6 outlines the simulation model and five target scenarios. These scenarios impact performance metrics, such as inventory levels and cycle service performance. Simulation results and model implementation are described in depth in this section. Finally as a wrap-up, chapter 7 offers opportunities for further research and chapter 8 highlights key conclusions.

2 HIV/AIDS Complexities

The HIV/AIDS supply chain differs from traditional operations because of treatment characteristics and the poor healthcare infrastructure in developing nations. Considerations regarding funding, shrinkage, human capital, and consumer behavior need to be accounted for in order to successfully manage the supply chain.

2.1 Treatment

HIV/AIDS patients high CD4 counts and viral loads are put on a lifelong treatment regimen called HAART, highly active antiretroviral therapy. This therapy includes single dose and fixed-dose combinations of two or three Antiretroviral (ARV) drugs from different medication categories. The following is a list of ARV groupings:

- Protease Inhibitors (PIs)
- Nucleoside/Nucleotide Reverse Transcriptase Inhibitors (NRTIs)
- Non-Nucleoside Reverse Transcriptase Inhibitors (NNRTIs)
- Entry Inhibitors (excluding Fusion Inhibitors)

Patients, on HAART, must take medications twice a day everyday. A 90-95% adherence to this regimen is required for treatment to be effective in the long run. HIV/AIDS is biologically adaptive. Patients who miss more than one dose every two weeks will develop drug tolerance. There are 1st and 2nd line patients. Patients are initially put on a 1st line treatment. Those that do no respond well to therapy or have built up drug

resistance are moved to 2nd line medication. 2nd line patients require higher dosages and must be monitored frequently. 2nd line and pediatric drugs are 10 to 50 times more expensive then first line treatment and may require cold-chain storage. Once HAART has been initiated, ARV drugs should be made available consistently to a patient over their life-time in order to maintain drug effectiveness. This puts tremendous pressure on supply chain functionality because of high stock-out risks and dosage variability dependent on patient medical needs.

Advances in modern medicine and improvements in treatment cost and delivery have made caring for those infected with HIV economically feasible. HIV positive patients can live long health lives under HAART. A common method for gauging the cost effectiveness of healthcare treatments involves looking at quality adjusted life years (QALYs). QALYs takes into account the number of years a patient's life is expected to be increased by treatment and adjusts based on the quality of life this therapy provides. According to a 2004 study initiated by the Medecins Sans Frontieres (MSF)[2], Cape Town patients on ARV treatment have an expected life of 6.79 quality adjusted years verses 1.59 for those left untreated. The estimated cost for a lifetime of treatment is $13,000 or approximately $1,900 per QALY ($13,000 / 6.79 QALYs). Generally, treatments are considered cost effective if it less than 3 times the gross national income (GNI) per capita. For Sub-Saharan Africa, the GNI per capita is approximately $735, thus making HAART a cost effective option.[3] Procurement discounts, especially for 2nd line and pediatric drugs, and process efficiencies can greatly help to lower the cost per quality adjusted life year and further expand treatment.

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[2] Médecins Sans Frontières (MSF) is an international humanitarian aid organization that provides emergency medical assistance to populations in danger.

[3] Source: World Bank, Sub-Saharan Africa GNI per Capita = $745

2.2 Developing Nation Environment

2.2.1 Funding

Besides the unique nature of HAART, other factors make the HIV supply chain difficult. There are burdening budgetary concerns. Financial funding relies heavily on public and private donations. Because of the extensive amount of paperwork involved with purchasing through multiple funding organizations, developing countries typically place an annual order and schedule 3 or 4 deliveries throughout the year. Forecasting accuracy for such an extensive period is difficult and coordination between various donors can be cumbersome. These issues that influence country operations also affect ARV suppliers. In working with the bureaucracy of nonprofits, it is hard for drug manufacturers to manage their revenue recognition cycles. Companies depend on these incomes to build additional capacity needed to meet increasing demand made available through nonprofit funding.

2.2.2 Shrinkage

Outside countries produce most HIV drugs distributed in Sub-Saharan Africa. Hurdles in getting these life-saving treatments past customs add to lead-time and lead-time variability. ARV medications have a shelf-life of 12 to 24 months and typically 25% to 30% of the shelf-life is gone by the time the drugs reach its destination. Furthermore, distribution in country can be challenging. These drugs are administered to remote areas where transportation is difficult. Delivery can be unreliable and lack the necessary measures to deter theft. Transportation methods must be secure, accountable, and in some cases equipped with temperature controls throughout the supply chain. High

lead-time variability and the common occurrences of shrinkage make the supply chain in developing countries tricky to manage. Shrinkage in this situation can be attributed to supplier inefficiencies, theft, and/or product spoilage.

2.2.3 Human Resources

Aside from appropriate supply chain policies and drug availability, there is an insufficient amount of human resources available to run an effective supply chain. It is difficult for developing countries to recruit and retain strong management and medical staff. This leads to drug orders not being placed and patients missing their dosages. The U.S. has over 51 times the number of physicians, 22 times the number of nurses, and 29 times the number of pharmacist in comparison to Rwanda for every 100,000 people[4]. See table 2 below. Appropriate policies in operations must account for these inefficiencies and lack of human capital.

Table 2: Medical Human Resources per 100,000 People

Country	Physicians	Nurses	Pharmacists
US	256	937	88
Dominican Republic	188	184	40
China	106	105	28
Bahamas	105	447	n/a
Jamaica	85	165	n/a
India	60	80	56
Botswana	40	265	19
Haiti	25	11	n/a
Cambodia	16	61	4
Kenya	14	118	10
Lesotho	5	62	3
Rwanda	5	42	3
Mozambique	3	21	3
Tanzania	2	37	1

[4] PLOS Medicine, www.plosmedicine.org, July 2006, Volume 3, Issue 7 – McCarthy, O'Brien, Rodriguez. Training and HIV Treatment Scale-up: Establishing an Implementation Research Agenda.

2.2.4 Consumer Behaviors

Consumer behavior makes demand management and quality patient care a major obstacle. It takes significant commitment on the patients' part to stick to a regiment of two doses a day. Those infected by HIV need to be educated on the disease and the importance of treatment adherence. Patients in developing countries have difficult transportation and financial hurdles. They cannot afford regular visits to a clinic. In general patients are required to visit a facility every month. Clinicians use this time to monitor treatment, make dosage adjustments, and distribute ARV drugs for the following month. HAART medication must be taken on a full stomach in order to reduce nausea and allow the body to keep drugs in the system. In Sub-Saharan African, there are over 300 million people living below the poverty level, or less than $1 per day (World Bank Report). They do not have consistent access to food and water. Patients in poor countries may be willing to adhere to treatment, but there are socio-economic factors that prevent them from receiving adequate care. All of these constraints affect consistent consumer behavior make demand management highly unpredictable.

2.3 Issues Summary

The aforementioned issues all contribute the complexity of the HIV/AIDS supply chain in developing countries. These factors make the system unique. Special considerations should be made to maintain adequate inventory levels and high cycle service levels. See figure 2 on the following page for a summary of the added considerations when operating in developing countries. The *Simulation Model* chapter

proposes ways to manage these issues and analyzes improvements that will have the greatest impact on providing consistent patient care.

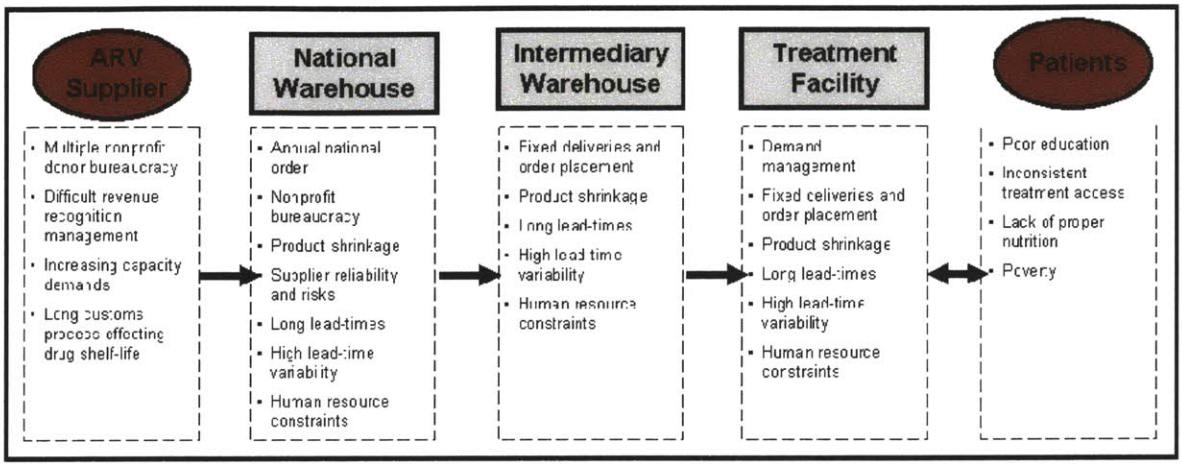

Figure 2: Supply Chain Complexities

3 Supply Chain Description

Developing nations structure and operate their HIV/AIDS supply chain differently. The information presented in this chapter and in the Previous Work section comes from literature research and interviews with nonprofit organizations. The objective is to understand the current situation and explore the common complexities mentioned earlier in figure 2. This section describes procurement, distribution, and inventory management policies in developing countries. The specific focus, illustrated through case studies, is on countries in Sub-Saharan Africa. These nations have the highest prevalence of HIV/AIDS.

3.1 Procurement

Procurement can be centralized, decentralized, or some combination of the two practices. Ideally, at the national level, governments should purchase centrally in order to have greater control over drugs arriving in country. All ARV drugs in Rwanda are purchased through a central source, but this is considered atypical. Generally, countries must purchase through a number of donor organizations all of whom have their own supplier preferences. A large order is placed for the year with 3 or 4 scheduled deliveries. These shipments usually take 4 to 8 weeks to arrive at the destination country. The Clinton Foundation HIV/AIDS Initiative advises their partnering nations to move towards a 70/30 percent split between two main suppliers. This allows for pricing discounts based on volume and a reduction in procurement risks by sourcing from multiple suppliers. Generic manufacturers supply the majority of drugs to Sub-Saharan

Africa. See table 3 and *Appendix I* for details.[5] Buying power and control are important in dealing with these producers, because although more inexpensive, there is a growing concern over the efficacy of unbranded prescription drugs.

Table 3: Manufacturer of ARV Drugs into Sub-Saharan Africa – 2004 to 2006 [6]

Manufacturer	Number of Units	Percentage
Other	1383544787	50.00%
Cipla Ltd.	530496763	19.17%
Aurobindo Ltd.	189293999	6.84%
GlaxoSmithKline Ltd.	121202502	4.38%
Boehringer Ingelheim	89690919	3.24%
Bristol-Myers Squibb	78353761	2.83%
Aspen Pharmacare Ltd.	71254790	2.58%
Hetero Drugs Ltd.	65697580	2.37%
Merck, Sharp & Dohme Ltd.	54836157	1.98%
Ranbaxy Ltd.	40918190	1.48%
Emcure	33168200	1.20%
Strides Arcolab Ltd.	31128180	1.12%
Hoffman La Roche	30897198	1.12%
Abbott Laboratories Ltd.	14283118	0.52%
IDA	12272000	0.44%
Roxanne Lab.	6224400	0.22%
Aspen Pharmacare	5765040	0.21%
Gilead Sciences, Inc.	3299490	0.12%
A to Z Textiles Limited	2574210	0.09%
IHD	532800	0.02%
Gilead Sciences Inc.	529830	0.02%
Ranbaxy Ltd..	399000	0.01%
Cadila	240000	0.01%
Geka Pharma	195600	0.01%
Patheon	122220	0.00%
Roxane Laboratories	72000	0.00%
To be verified	54000	0.00%
UNICEF Warehouse	41640	0.00%
Meymac	600	0.00%
Star Pharmaceuticals Ltd.	600	0.00%
Grand Total	2767089574	

Local purchasing differs slightly from national policies. Countries that have well-trained staff at the local administering level will utilize a "pull" ordering system, while centrally efficient programs will utilize a "push" system. Some may use both types of procedures based on the characteristics of the individual dispensing site. At both the national and local level, countries generally order in fixed periods because of the arduous task of effort coordination and transportation management.

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[5] World Health Organization Global Price Reporting Mechanism
[6] Highlighted manufacturers produce branded drugs.

3.2 Distribution

Distribution networks also appear to be different from country to country, but there are some commonalities. Typically there is a national warehouse and intermediary warehouses that supply large hospitals and local clinics with first-line ARV medications. The demand for second-line treatment is much smaller, so countries with reliable quick transportation systems, less than 24 hours, will store these products at a national facility. Ordering and transportation can be handled at the warehouse level or by the administering facility. In Rwanda, patient interfacing locations place their orders with a warehouse and are responsible for arranging transportation and shipment pick-up. Since Rwanda is rather small, approximately 26,000 square kilometers or slightly more than twice the size of Los Angeles county, transportations take less than a couple of days even despite the rural transportation networks. In more sophisticated systems, distribution is controlled centrally. Transportation runs may be triggered by an order placement or be routine. Some areas will incorporate a "milk-run" scenario. A truck will routinely visit a set of sites. In these visits, the truck will replenish supply and pick up products that are close to expiration. These drugs are then redistributed to facilities for immediate administering. Regardless of the level responsible for transportation, distribution must be reliable and secure because of the sensitivity of ARV drugs.

3.3 Inventory Policy

Locations determine order quantities based on inventory management policies. This is similar to practices in traditional supply chains. Much like procurement and distribution, inventory management will either be controlled centrally or at the local sites

depending on which level is run most efficiently. The standard policy, as considered by USAID, is a (R, s, S) system. With this setup, facilities review inventory every R periods. Once inventory levels hit a point s, product is ordered up to a quantity S. In a (s, S) system inventory is reviewed continuously. Product is ordered up to a point S, once inventory levels fall below a point s. Lastly, there is a two-bin variation of the continuous review system. Two bins are each filled with enough supply to meet demand for a given period of time. Once all the drug treatment is gone from one bin, product is ordered to fill the emptied bin. All of these policies are reasonable, but the policy looked at in this research model is an (R, S) model. The *Model Design* section describes reasons for an (R, S) selection.

3.4 Case Examples

3.4.1 Kenya

Figure 3 illustrates a USAID study done in Kenya in 2004. The diagram shows organizations that contribute to funding, procurement, warehousing, and delivery at the district and sub-district levels. A major procurement issue for Kenya, which likely exists with other under-developed African countries, is the consuming task of ordering through multiple donor organizations. Anti-retroviral drugs go through 4 different funding sources and 6 different procurement agencies in Kenya. Synchronization concerns contribute to complications involved with scheduling and demand planning.

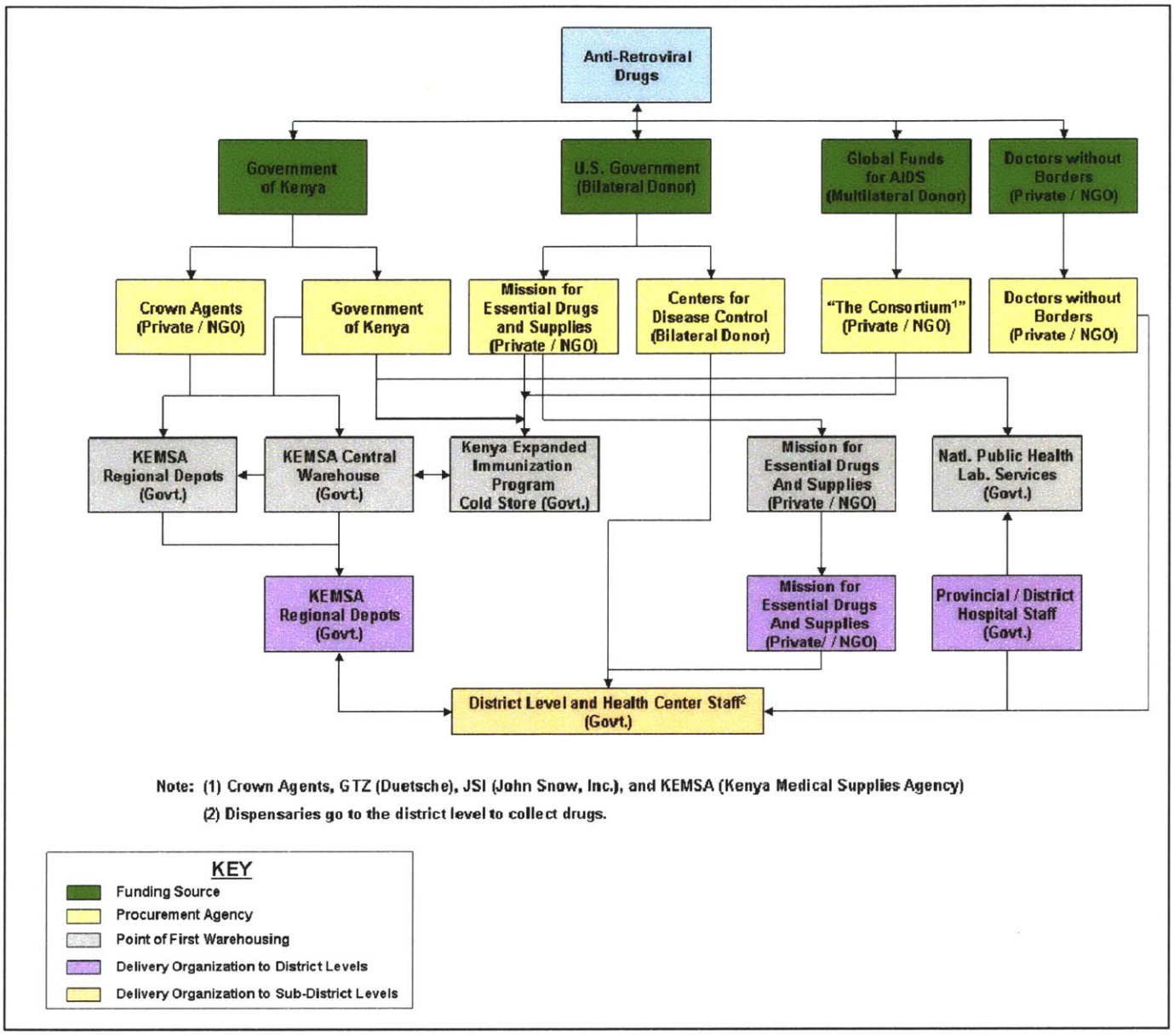

Figure 3: Kenya Logistics System 2004

ARV drugs in Kenya are distributed through three different sectors: public, private, and mission (religious).[7] Within the public sector there is 1 central warehouse (KEMSA in Nairobi), 7 regional warehouses, 2 national hospitals, 8 provincial hospitals, and 78 district hospitals which serve the health centers and dispensaries. The central and

[7] Interview with John Snow, Inc.

regional warehouses distribute to the hospitals, which order every 2 months. The central warehouse pushes orders out to the regional warehouse. National and provincial hospitals can schedule pick-ups or deliveries, while all district hospitals receive deliveries. Once an order is placed, it takes 4 to 6 weeks for this order to arrive at the hospitals. Health centers and dispensaries in this case do not administer ARV drugs. The public sector treats approximately 70,000 patients in Kenya.

3.4.2 Uganda

The Ministry of Health and the Danish International Development Agency purchases essential drugs in Uganda. The National Medical Stores in Entebbe (NMS) manages logistic operations.[8] Uganda has 56 district and 214 sub-district storage facilities. Distribution operates on a "push" system where a central organization determines order quantities and scheduling for all channels. The NMS delivers drugs to the district warehouse, which subsequently repackages for transportation to the sub-district locations. Four trucks are used to service the entire system. Current lead-time including processing, transportation, loading, and unloading time takes approximately 59 days at the district level. For Uganda, fuel and maintenance is $.63 per kilometer, travel per diem is $14.45 per day per truck driver, and standing costs are about $110.22 per vehicle per day.

[8] Deliver. Analyzing Transportation Costs Uganda. *On Track.* April 2003

4 Previous Work

There has been extensive research in resource allocation in regards to global policy making, but the purpose of this paper is to address the problem of HIV/AIDS from a tactical level. Many nonprofit organizations contribute to work in this arena. Specifically, this section looks at the efforts of the Institute of Healthcare Improvement, Clinton Foundation, Center for Disease Control, USAIDS, and Partners in Health. Information is based on literature research and field interviews. The Institute of Healthcare improvement targets benefits through process improvement. The Clinton foundation takes an advisory role in negotiating ARV procurement discounts and in addressing the lack of human resources in the healthcare profession. The Center for Disease Control, through its Sustainable Development and Management program, works to train effective leaders in managing the efforts against the spread of HIV/AIDS. In targeting multiple areas of the supply chain, USAID has developed a variety of tools to help developing countries assess and improve their operational activities. And lastly, Partners in Health, through its HIV Equity Initiative in Haiti, has developed a unique approach in addressing the prevention, treatment, and education of HIV/AIDS.

4.1 Institute for Healthcare Improvement

The Institute for Healthcare Improvement (IHI) was founded in 1991. It is a nonprofit organization that originally focused on improving the health care system in developed countries, but has recently expanded its work into poor nations. Specifically,

IHI works to increase availability and access to HAART through process improvement. IHI and its partners currently support several projects in South Africa. Rural projects are in Umkhanyakude District and Mhlontlo District (Eastern Cape), and urban projects are in Cape Town metro (Western Cape) and Johannesburg.[9] IHI's focuses its approach on achieving benefits that do no require an extensive amount of human and material resources. In the Eastern Cape, IHI increased the number of patients that initiated monthly on treatment from 12 to 35 through process changes and the spread of HIV/AIDS awareness. IHI believes the most effective way to combat HIV/AIDS is to optimize the existing healthcare system while securing resources needed for widespread treatment.

4.2 Clinton Foundation

The Clinton Foundation HIV/AIDS Initiative (CHAI) works to combat the spread of disease through drug discounts and integrated care programs, e.g., treatment and prevention. In 2005, over 30% of the Clinton Foundation expenses, approximately $40M, were spent on HIV/AIDS programs (2005 Annual Report).

CHAI's Procurement Consortium is among these programs. The Procurement Consortium allows developing countries to access ARV drugs at affordable prices. Nearly 90% of drugs purchased in Sub-Saharan Africa are through generic manufacturers. See *Procurement* section. On October 23, 2003 an agreement was established with 5 generic manufacturers: Aspen Pharmacare Holdings, Cipla, Hetero

[9] "The Science of Dissemination: Strategies for Scale-up Antiretroviral Treatment in South Africa Through Health System Optimization"

Drubs, Ranbaxy, and Matrix Laboratories. These companies allow the CHAI team to identify areas for cost savings within their operations in exchange for pricing discounts based on volume contracts. CHAI teams focus on lower manufacturing costs and formulation overhead for generic companies. Over 60 partner countries have access to this pricing agreement. The World Health Organization has approved all drug therapies included in the agreement for quality and efficacy. Four years ago the price of treating a patient on ARV medication for one year was over $500. The Clinton Foundation has reduced these prices by nearly two-folds. See figure 4 for price comparisons. In addition, CHAI launched the Pediatric and Rural initiative in 2005. Through this effort, CHAI is working to reduce the prices of pediatric and 2nd line HIV/AIDS treatment and diagnostic tests. These medications are more expensive primarily because of a lack of competition by generic manufacturers.

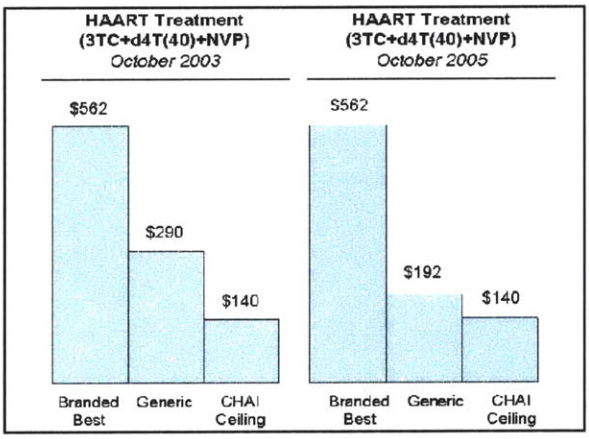

Figure 4: CHAI Negotiated Price Comparison (Annual Treatment Cost per Patient)

CSHOR, Consortium for Strategic HIV Operations Research, is a new program division within CHAI. CSHOR works with low and middle income countries to improve treatment and care. This program addresses the lack of resources and infrastructure available to support widespread HAART treatment. CSHOR has developed a simulation

tool, SIMCLIN, that analyzes resource requirements for drugs, lab testing, and human resources. The model predicts future healthcare needs and the impact of change at the administering level. Formulation inputs include data regarding population and treatment protocol. This initiative works to improve the recruiting, training, and retention of necessary healthcare workers in developing countries.

4.3 Center for Disease Control (CDC)

The Center for Disease Control (CDC), similar to the Clinton foundation, views human resource as an important area for improvement, but their focus is at the management level. The CDC sponsors a Sustainable Management and Development Program (SMDP). The goal of this program is to strengthen public health management and leadership in developing countries. SMDP partners with the Ministry of Health, Non-Government Organizations (NGOs), and academic institutions. SMDP offers a six week training course in the Management of International Public Health (MIPH). Enrollees are local counterparts from the CDC Global AIDS Program (GAP) and developing country representatives. Once completing MIPH, the CDC sends these representatives back to their host country. They are then responsible for using the tools and techniques provided by SMDP to train individuals in middle management, e.g., lab managers, warehouse coordinators, etc. The Center for Disease Control has taught nearly 300 people from 61 countries, who, as a result, have trained over 3000 public health professionals. Table 4 on the next page details the core competencies of SMDP.

Table 4: CDC SDMP Core Curriculum

Managing in an Organization	Managing Public Health Programs	Managing in a Changing Environment	Training of Trainers
• Team Building • Effective Communication • Behavioral Style Analysis • Leadership • Conflict Management • Strategic Communication • Time and Meeting Management • Supervision	• Priority Setting • Health Problem Analysis • Intervention Strategy • Work Plans and Program Budgets • Monitoring and Evaluation • Problem Solving/Evidence-Based • Decision Making • Process Improvement	• Leading Change for Results • Advocacy • Communication and Media Relations • Crisis Communication • Organizational Excellence	• How to Manage, Design, Deliver, • Evaluate Training • Effective Presentation Skills

Often SMDP workers will visit a developing country as mentor. They will collaborate with the country representative in management development efforts. For eample, SMDP helped the Machinga District Hospitals in Malawi. 65% of the hospitals in this district were experiencing low detection rates of smear-positive tuberculosis patients because of laboratory handling errors. Through training and process improvements, the percentage of underperforming hospitals dropped from 65% to 50%. SMDP's approach is to train strong managers to lead the efforts against HIV/AIDS.

4.4 USAID

USAID is an independent government agency that operates under the guidance of the Secretary of State. The purpose of this organization is to further America's foreign policy interests and improve the lives of those in the developing world. The USAID DELIVER project focuses on supply chain operations. DELIVER has developed several tools for managing operations. These tools help organizations assess their current supply chain situation and in some instances output concrete operational decisions, e.g., forecasting

figures, procurement quantities, etc. See table 5 for a list of USAID tools and functionality.

Table 5: USAID Tool Description

USAID Tool	Description
Logistics System Assessment Tool	The Logistics Systems Assessment Tool (LSAT) is used to diagnose and monitor the supply chain environment. Organizations can apply this tool to identify potential issues or areas for improvement.
Logistics Indicators Assessment Tool	The Logistics Indicators Assessment Tool (LIAT) collects data in order to calculate key logistics indicators, e.g., data accuracy for inventory management, percentage of facilities that receive product quantities ordered, percentage of facilities with acceptable storage conditions, stock status, and stock-outs.
Logistics Management Information System	Logistics Management Information (LMIS) helps forecast future needs, plan procurement, maintain adequate inventories, and ensure routine distribution of orders .
Assessment Tool for Laboratory Services	Assessment Tool for Laboratory Services (ATLAS) is comprised of three questionnaires for various levels in distribution system: central administrative, intermediate administrative, and facility (laboratory). This tool is used to capture the perspective of various stakeholders and facilitate group discussion.
Stages of Readiness	Stages of Readiness helps to assess a facilities ability to introduce or expand HAART therapy, specifically in six key areas: leadership and program model, services and clinical care, management and evaluation, human resource capacity, laboratory capacity, and drug management and procurement.
Pipeline	The PipeLine is a forecasting software utilized for procurement decisions. Forecasting is based on actual consumption data or quantities issued from warehouses or storerooms upstream.
Process Mapping	Process Mapping identifies inefficiencies in the system by comparing work activities to established policies and procedures.

4.5 Partners In Health

Founded in 1987, Partners in Health (PIH) is a nonprofit organization that focuses on delivering quality health care to developing communities. PIH benefits from strong alliances with Harvard Medical School, Harvard School of Public Health, and the Brigham and Women's Hospital. Partners in Health launched their HIV Equity Initiative in Haiti in 2000 with the help of a $44.7M grant from the Bill & Melinda Gates Foundation. This effort is based on PIH's "four pillars": AIDS prevention and treatment, advanced tuberculosis care, improved screening and testing, and women's health.

Tuberculosis is the leading cause of death among those suffering from HIV/AIDS. The focus on women's health is on reducing maternal mortality, preventing mother-to-child transmission, and early detecting of HIV in newborns. The supply chain that resulted from this effort is unique. Free ARV medications are provided to the community through "Accompagnateurs". Accompagnateurs are local Haitians trained to administer ARV drugs. They travel to patients daily and serve as a link between the villages and the clinics. Accompagnateurs, some who may be HIV positive, test patients, deliver therapies, ensure adherence, and attend to social problems, such as malnutrition, housing, education, and psychological support. As a result, PIH has lowered AIDS mortality in impoverished areas and have since expanded into Sub-Saharan Africa.

5 Threat of Widespread Resistance

The aforementioned supply chain complexities contribute to inconsistent HIV treatment, which can then result in widespread drug resistance. Chapters 2 through 4 highlighted issues in the developing world and chapter 6 identifies five process scenarios that impact service level and inventory management. High service levels come at the expense of increased inventory. Although excess drug inventory causes system waste, the long-run cost of missed dosages far outweighs the immediate financial burdens of purchasing and holding extra product. This chapter seeks to analyze the economic impacts of poor patient care.

Patients that miss treatment tend to build a tolerance to drug effectiveness. Patients are required to take their medication everyday and HAART becomes ineffective if more than one dose is missed every two weeks. Resistant patients are more expensive to treat. Cynics of nonprofit programs in developing countries believe that these initiatives provide greater opportunity for HIV viruses to mutate and spread. In contrast, "Staying the Course", an article in Nature, states that widespread resistance is not a threat because patients in Africa are just as likely to adhere to treatment as those in the developed world.

Although individuals in developed and developing countries have demonstrated commitment to HIV therapy, there are additional issues to consider in understanding the potential for widespread resistance in resource-poor environments. The development and spread of resistant strains as an outcome of inconsistent treatment, is not dependent on one country's performance relative to another. Poor patient care is a global issue and will

lead to the spread of a mutated disease if not managed properly. Furthermore insufficient funding can result in inconsistent treatment. Patients in developing countries treated in the government nonprofit sector do not have control over their healthcare funding as opposed to those who are financial independent. They may be willing to adhere to treatment, but are unable to due to socioeconomic factors. Additionally, patients in poorer countries might just as likely develop a resistant strain as those in the developed nations, but they may be more prone to spreading the disease. According to a study published in the Journal of Community Health, people in underdeveloped nations are less knowledgeable about HIV/AIDS facts, prevention, screening, and treatment. In this study a high-risk pool[10] of Russian and U.S. citizens were surveyed on HIV/AIDS knowledge. On average 56% of Russians and 74% of U.S. citizens answered questions accurately. Inadequate HIV/AIDS education results in disease spread due to late detection or false assumptions regarding transmission, e.g., sex protection, needle sharing, etc.

Since HIV/AIDS is biologically adaptive, poor patient care will have an adverse effect on the efforts to lower HIV/AIDS mortality rates. Fortunately, according to a study by MSF, only 4.4 out of a 1000 patients in developing countries are expected to switch to 2nd-line treatment each year. Widespread resistance has not yet emerged, but the threat is imminent if measures are not taken to keep the disease from mutating and spreading. Quality uninterrupted treatment is needed in both the developing and developed worlds in order to avoid the devastating ramifications of suboptimal healthcare. The consequence of drug resistance includes treatment failure, health cost increases, resistant strain transmission to treatment-naïve individuals, and new anti-HIV

[10] African-American, Russian, single, 29-25 years old

drug development. Quantifying this threat is difficult because sufficient data collection methods that capture the prevalence of HIV resistant strains among treated and untreated subjects do not currently exist.

The importance of dependable HAART accessibility makes a well designed supply chain critical. Operations must be robust and flexible to account for the complexities of the environment and provide quality consistent patient care. If widespread resistance becomes more evident, a properly designed system will go a long way in battling HIV/AIDS. An important performance measure in the simulation model is patient service. Identifying scenarios that help improve this metric in the short-run can greatly help to lower HIV/AIDS related deaths in the long-run.

6 Simulation Model

The goal of this research model is to look at areas of improvement in the entire HIV/AIDS supply chain while accounting for some of the complexities previously mentioned. Most of the nonprofit initiatives target specific improvement areas, but a supply chain can only operate as efficiently as its weakest link. It is important to understand the relationships between the different nodes in the system, because changes in one area will undoubtedly result in a rippling effect. Furthermore, the tools developed by USAID and CHSOR can be data dependent. This poses a problem given that a majority of facilities in the developing world have unsophisticated IT systems, and the minimal data available tends to be inconsistent and unreliable. Additionally, although Partners in Health's approach may be ideal, most resource constrained nations lack the infrastructure to support such a set-up, which requires extensive human resource and operational restructuring.

This research analyzes the problem at an integrated supply chain perspective. The model is intended to help organizations understand their supply chain issues and optimize their current operating environment. The simulation developed in this chapter does not require a significant amount of data and looks at the interaction between a distribution center and multiple administering sites. Understanding the interaction between upstream and downstream operations and integrating the two can yield significant benefits. These benefits include improved customer service, faster response times, and reduced inventory investments and write-offs (Hau Lee, "Creating Value Through Supply Chain Integration"). The model addresses the problem of HIV/AIDS by analyzing it from a

systems approach and targeting improvement areas that will yield the most desirable outcomes.

6.1 Model Design

The simulation is designed in Microsoft Excel and is intended to be customizable to different operating environments. Each run includes 3 years of simulated data. Ideally, countries can use this simple approach to understand their operations and its effects on inventory and customer service levels. Inventory management is based on a (R,S) policy. Every R periods, product is ordered up to a level S. Although USAID considers a (R, s, S) policy as standard, an (R, S) system makes sense because of researched information and the baseline data used in the model. Locations typically order in fixed intervals, hence the need to include set review periods, R. Furthermore, review periods tend to be longer than lead-times. In these instances, the minimum point s in a standard (R, s, S) system becomes the maximum level S.

The analysis considers one warehouse and two administering sites. The warehouse receives ARV drugs coming in-country from 3 suppliers and is the sole distributor to both sites. Supplier lead-times to the warehouse and the local sites are simulated as a normal distribution. Although HAART can be complicated, see Treatment section, a monthly dose is considered to have the appropriate ARV drug combinations for a month's supply. Patient arrival and demand is modeled as a Poisson distribution. Patients arrive into the system monthly to receive treatments for a 4 week period.

6.2 *Baseline Data and Assumptions*

The data used as baseline is considered reasonable according research and interview findings. The total yearly demand for the two sites combined is 18,000 monthly treatment doses. On average, 25 patients arrive into the system daily at each site with a standard deviation of $\sqrt{25}$ or 5 patients per day.[11] The warehouse places orders every 3 months and sites order every 2 months. Three suppliers service the warehouse. Orders are divided equally among these suppliers. Warehouse supplier lead-time is 6 weeks plus or minus 2 weeks. Processing time between the warehouse and local sites is 5 weeks plus or minus a week. See figure 5 and table 6 for model details and assumptions.

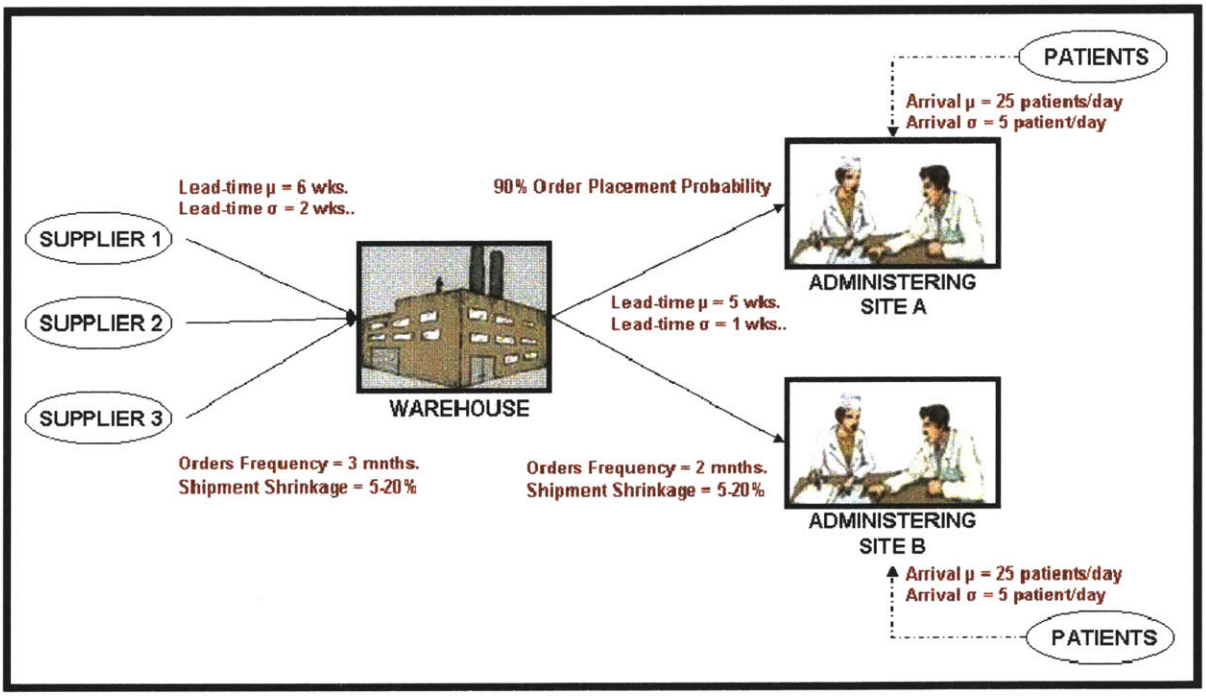

Figure 5: Model Diagram

[11] Calculation is based on the Kenya example. With 70,000 patients on treatment and approximately 88 treatment sites, each site will treat approximately 800 patients. Patients arrive every month to receive their monthly treatment dosages. 750 is assumed for calculation ease, therefore approximately 25 patients arrive to a site daily.

Table 6: Model Assumptions

- (R,S) inventory policy
- Pull ordering system at the warehouse and local level
- 3 warehouse suppliers with evenly distributed orders
- Warehouse delivery is every 3 months
- Sites order every 2 months
- Normally distributed lead-times
- Poisson distributed patient arrivals
- Site A has priority ordering over site B
- Discrete site ordering probability – 1 if order is placed, 0 otherwise
- Warehouse scheduled delivery quantities can be adjusted
- Monthly treatment dosages are tracked in the model

As mentioned, the supply chain in the developing countries differs from traditional operations. Some of these externalities have been incorporated into the model. A shrinkage factor is applied to shipments arriving to the warehouse and the sites. Shrinkage can be due to supplier reliability, spoilage, or theft. Normal shrinkage is considered to be 5%, but due to the complexities of this system, the simulation factors in a 5-20% shrinkage percentage. Furthermore, due to resource issues, an order probability is considered at the site level. For baseline analysis, the model assumes that there is a 10% chance that an order is never placed because of poor management or resource limitations. Order probability is simulated as a discrete distribution (order placed = 1 with a 90% probability and order not placed = 0 with a 10% probability). Data for lead-times, patient arrival, and shrinkage are simulated in this model using the rand() function in Microsoft Excel.

Inventory management calculations are based on textbook formulations in "Inventory Management and Production Planning and Scheduling" (Silver, Pyke, and Peterson). An order-up-to level, S, for the warehouse and sites is calculated using

equation 1. A model screenshot and excel calculations can be found in *Appendix III* and *IV*.

Equation 1: $S = x_{L+R} + k\sigma_{L+R}$, where

- **L = Lead-time (days)**
- **R = Review period (days)**
- **x_{L+R} = Demand over lead-time and review period**
- **k = Safety stock factor**
- **σ_{L+R} = Standard deviation in demand over lead-time and review period**

The standard deviation in demand over the lead-time and review period is calculated using equation 2. Table 7 shows the safety stock factor for each corresponding theoretical cycle service level. Cycle service level is calculated as the number of stock-out occasions in a year period. An increase in safety stock factor leads to an increase in the order-up-to level.

Equation 2: $\sigma_{L+R} = [E(LT+R)\sigma_D^2 + E(D)^2\sigma_{LT+R}^2]^{1/2}$, where

- **E(LT+R) = Expected lead-time plus review period (days)**
- **σ_D = Standard deviation in demand per day**
- **E(D) = Expected demand per day**
- **σ_{LT+R} = Standard deviation of lead-time plus review period**

Table 7: Safety Stock Factor

Safety Stock Factor	Theoretical Cycle Service Level
1.28	90%
1.41	92%
1.55	94%
1.75	96%
2.05	98%
3.72	99.99% ≈ 100%

As mentioned, orders at the national level, which go through multiple donor organizations, are placed once at the beginning of the year. Shipments from the various suppliers arrive periodically throughout the year. A major assumption in the model is

that these shipment quantities to the warehouse can be adjusted according to inventory levels at a given time. It is extremely difficult to predict and plan for yearly order quantities that will yield acceptable service levels. Countries, bureaucracy and finance permitting, should move towards a more flexible ordering system. This model uses an (R,S) policy to determine shipment quantities to the warehouse. If this operationally is unfeasible, the results from this simulation can be applied through back calculations to better determine annual shipment sizes.

6.3 Scenario Testing

Different scenarios were tested to see how they affect bottom-line metrics. The performance measures are average inventory level, cycle service level (CSL), and missed monthly treatment dosages. These metrics have important economic implications as discussed in chapter 5. Each model run includes data for 3 years. The warehouse and sites are originally stocked with enough inventories to meet order-up-to requirements for a particular cycle service level. Average inventory level is calculated over the last two years. Scenario results are computed by running the simulation 10 times and then averaging over all results. The following is a list of scenarios tested:

- **Scenario 1: Baseline Comparison**
- **Scenario 2: Increased Patient Demand**
- **Scenario 3: Increased Site Order Placement Probability**
- **Scenario 4: Decreased Lead-Time Variability**
- **Scenario 5: Decreased Shipment Shrinkage**

Scenario 1 compares simulation cycle service level results with theoretical cycle service level expectations. Scenarios 2 through 5 are factors that countries can work to improve. These factors affect the key performance measures analyzed in this study. The scenarios are tested using order-up-to levels that yield a theoretical cycle service levels of 99.99%. Site results are computed by averaging simulation results from both treatment administering locations.

6.4 Scenario Results

6.4.1 Baseline Comparison

In scenario 1, Baseline Comparison, the added externalities, e.g., shrinkage and order placement probability, yielded cycle service levels that were lower than theoretical expectations. See table 8 for order-up-to levels corresponding to each safety stock factor and figure 6 for results. Order-up-to levels were calculated using equations (1) and (2) from above. Simulated warehouse cycle service levels were on average about 4% lower than theoretical values and site cycle service levels about 14% lower. This discrepancy was due to factors incorporated in the model that are not typical considered in normal supply chain operations.

Table 8: Inventory Levels Corresponding to Each Safety Stock Factor

Theoretical Cycle Service Level	DC Order-Up-To Level (monthly doses)	Site Order-Up-To Level (montly doses)
90%	7,413	2,575
92%	7,500	2,598
94%	7,605	2,625
96%	7,743	2,660
98%	7,957	2,716
100%	9,130	3,018

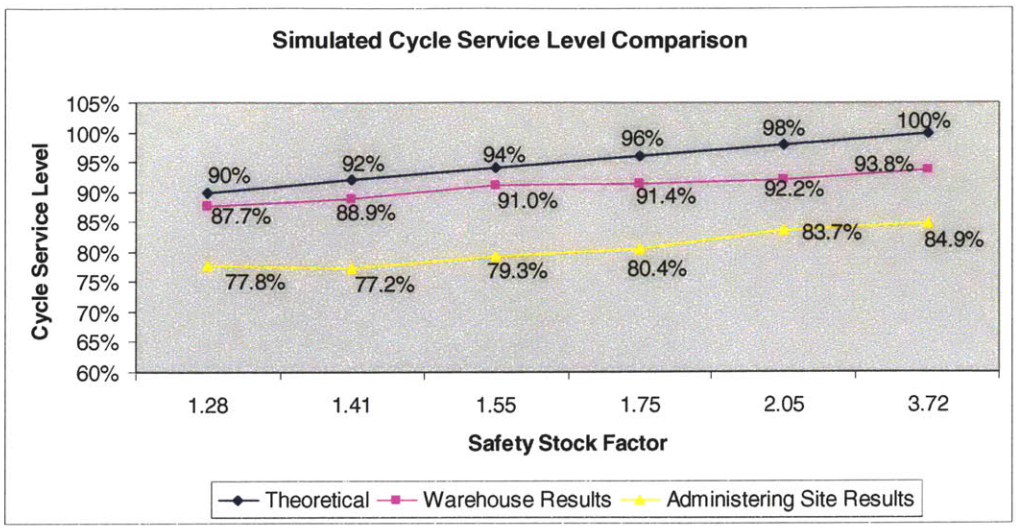

Figure 6: Scenario 1 – Baseline Comparison Results

Warehouse inventory policies required order-up-to levels of over 10 months-of-supply (15,000 doses) for a simulated cycle service level of 99%. Simulated average inventory levels for this were nearly 2.7 times more than the results from a safety stock factor of 3.72 (theoretical CSL = 3.72). See figure 7 on the following page. Similarly, more than 8 months of supply (6,000 doses) were required at the administering sites. This yielded an average inventory level of 7,943 monthly treatment dosages, which was 4 times greater than the amount of inventory needed for a CSL of 84.9%. 84.9% was the resulting simulation site service level with a safety stock factor of 3.72 (theoretical CSL = 99.99%). Again, these differences in simulation and expected results were due to system complexities. See figure 8. The graphs in figure 7 and 8 clearly illustrate the trade-off of purchasing and holding excess inventory for higher service levels.

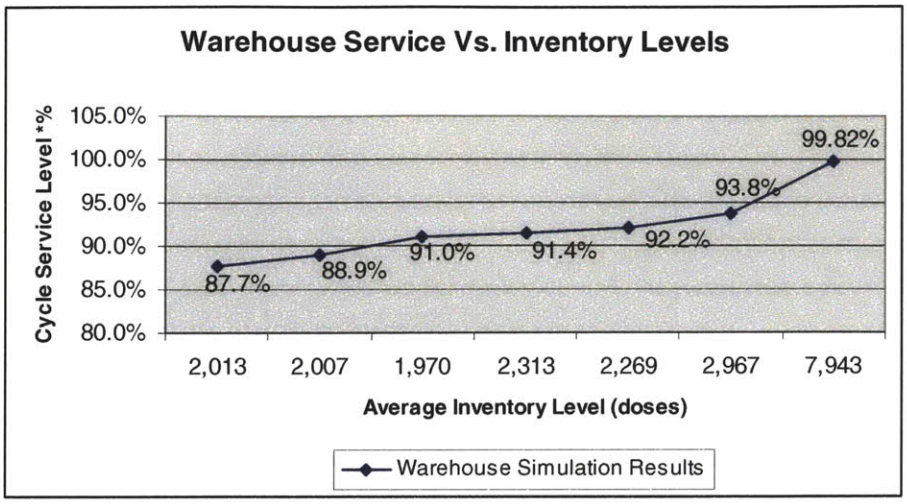

Figure 7: Simulation Warehouse CSL vs. Average Inventory Levels

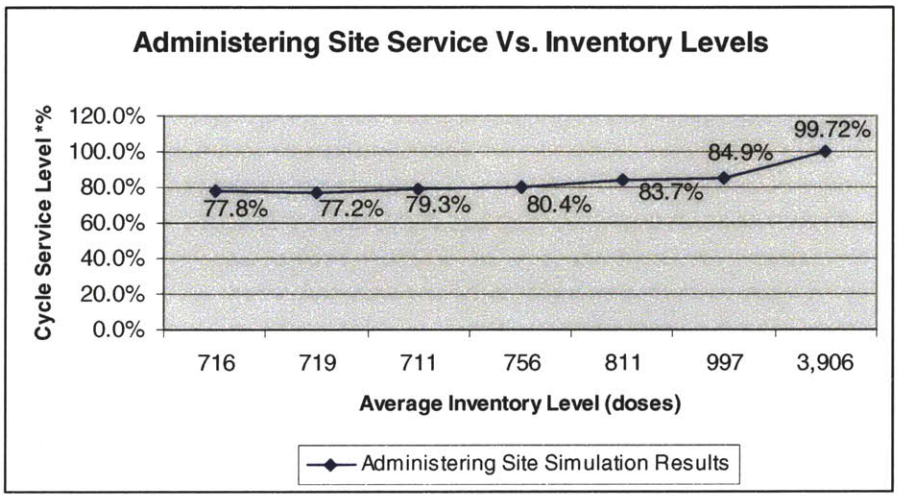

Figure 8: Simulation Site CSL vs. Average Inventory Levels

6.4.2 Increased Patient Demand

In this scenario the number of patients expected to arrive daily into the system was increased from a baseline of 25 to 30 patients. Increasing the number of patients treated at a site showed a drop in cycle service levels for both the warehouse and sites. See figure 9. Warehouse cycle service level worsened by nearly 3%. Average site inventory levels decreased, but service dropped by about 9%, which resulted in nearly double the number of patients who missed their monthly treatment dosages. The purpose

of this example is to illustrate how poor demand management can impact the system. Employees at administering sites may view themselves as good samaritans by treating more patients, but if excess demand is unplanned for, this type of behavior can lead to undesired outcomes in the entire system. This is especially critical in situations where demand and shipment sizes are forecasted a year in advance.

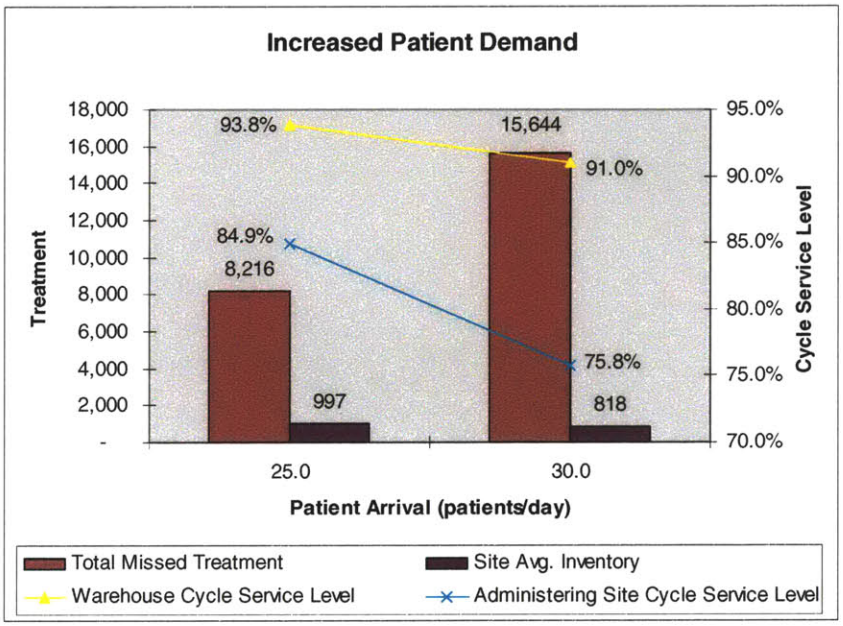

Figure 9: Scenario 2 – Increased Patient Demand

6.4.3 Increased Site Order Placement Probability

Scenario 3, Increased Site Order Placement Probability, shows how improvements in management and resource training can improve cycle service levels. The baseline order probability was set at 90%. An initial 5% increase in order placement probability at each site led to a nearly 5% improvement in service and an over 30% decrease in monthly missed dosages. When order probability increased from 95% to 99%, site cycle service level increased by slightly over 1%. This impact was less

dramatic in comparison to the initial 5% improvement from 90%. Increased inventory levels logically occurred as order placement became more consistent.

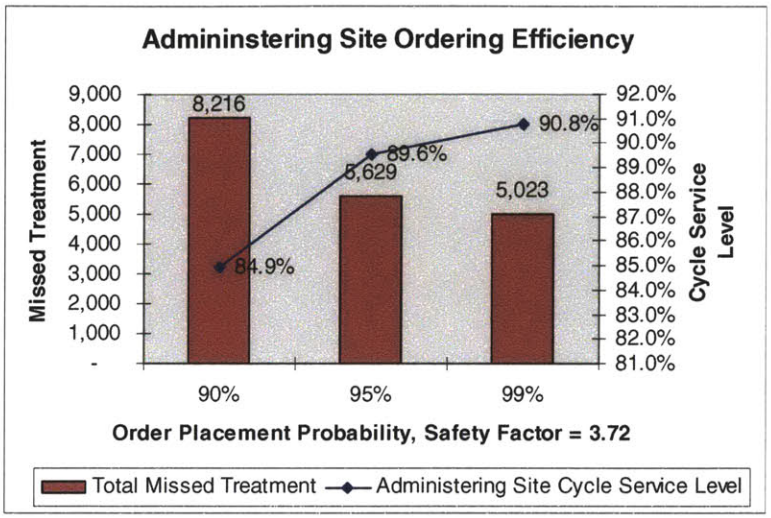

Figure 10: Scenario 3 - Increased Site Order Placement Probability

6.4.4 Decreased Lead-Time Variability

Scenario 4, Decreased Lead-Time Variability, explores the impact of decreasing lead-time variability on the key metrics. Decreasing lead-time variability from the supplier to the warehouse was not tested. With the baseline data used, this decrease would have had little impact on service level improvement and would have likely lead to an increase in average inventory level. The supplier lead-time to the warehouse is 45 days with a standard deviation of 14 days. Orders are placed from the sites to the warehouse every 2 months. This means that there is less than a 10% chance a supplier shipment to the warehouse will arrive after the next site order is placed, or equivalently the probability that warehouse supplier lead-time exceeds 60 days. Additionally, since the warehouse shipment is equally divided among three suppliers, the probability that all supplier shipments, in a given order interval, arriving after 60 days is less than .001%

(.1[3]). Consequently, this change would not have improved warehouse cycle service level and would have likely resulted in an increase in average inventory levels during ordering intervals.

In contrast, decreasing lead-time variability at the sites improved site service and consequently lowered the number of missed monthly patient treatment dosages. See figure 11. A 50% reduction in lead-time variability improved site cycle service level by almost 2%. Average inventory levels increased slightly, but missed patient dosages decreased by 11%. Countries can work to improve lead-time variability through better communication with transportation carriers.

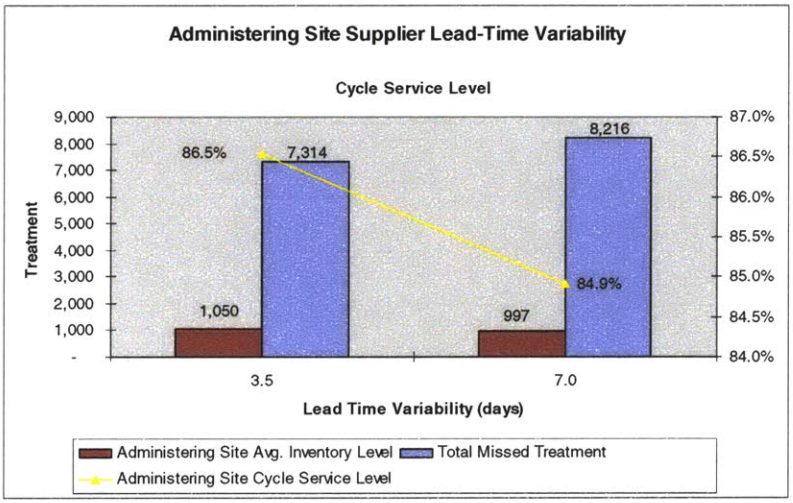

Figure 11: Scenario 4 - Decreased Administering Site Lead-Time Variability

6.4.5 Decreased Shipment Shrinkage

Lastly, decreasing shipment shrinkage resulted in improvements at the warehouse and site level. Again, shrinkage can be due to supplier reliability, spoilage, and theft. Better system communication and coordination will improve supplier reliability and solid manufacturing contracts can help reduce spoilage. Countries should refuse to accept

products with shelf-lives below a reasonable amount. Furthermore, investments in additional facility and transportation security can assist in deterring product theft.

The baseline level of shrinkage considered for the warehouse and sites is 5-20%. Improvements in warehouse shipment shrinkage led to increased cycle service levels for both the warehouse and the sites. Warehouse service level improved by about 1% for every 5% decrease in shipment shrinkage. Inventory levels increased for both the warehouse and sites. The initial 5% improvement in warehouse shipment shrinkage resulted in a 4% increase in site service and a 25% decrease in missed monthly dosages. See figure 12 below.

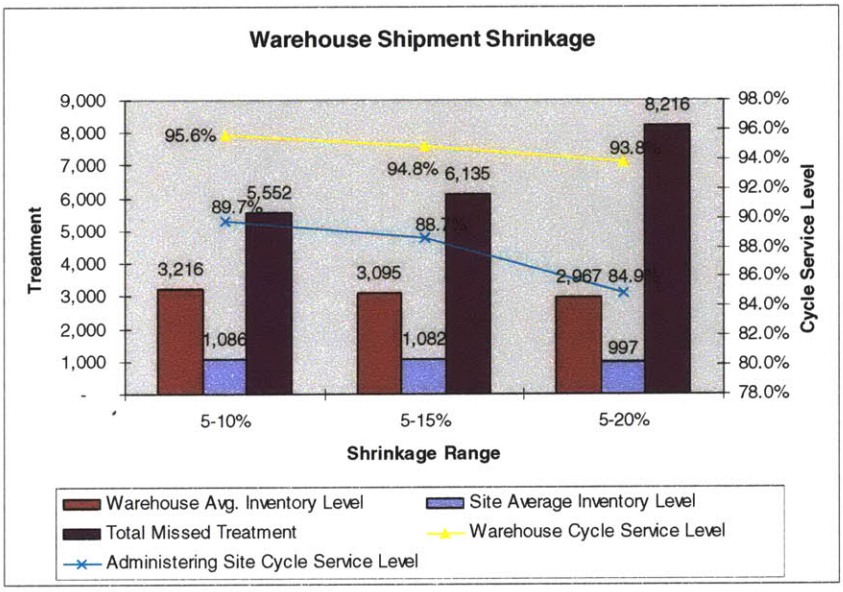

Figure 12: Scenario 5 – Decreased Shipment Shrinkage at the Warehouse Level

Figure 13 shows the results in decreasing shipment shrinkage at the local sites. Average inventory levels increased between 5 to 10 percent. Missed treatment dosages decreased by over 24% for the first 5% improvement in shipment shrinkage. The

decrease in missed treatment corresponded to a 3.6% improvement in administering site cycle service level.

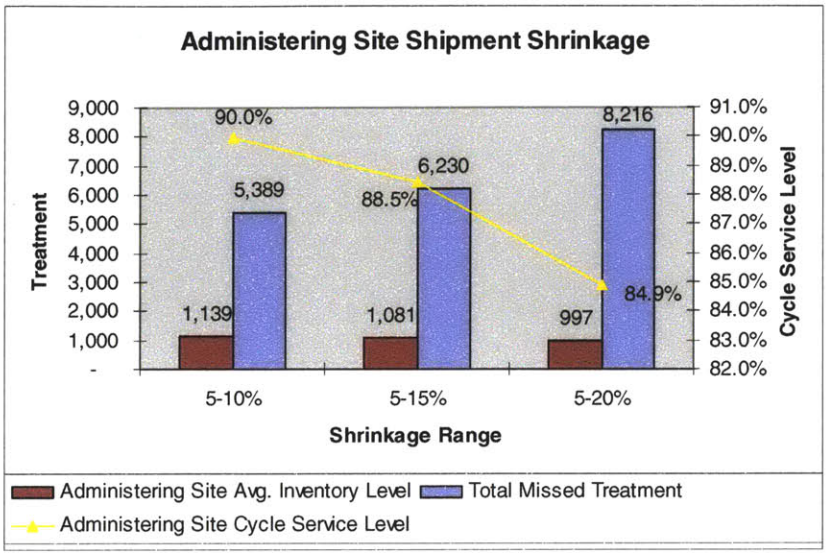

Figure 13: Scenario 5 – Decreased Shipment Shrinkage at the Administering Sites

6.5 Results Summary

Tables 9 through 13 summarizes the results of each scenario on warehouse and site service, warehouse and site inventory levels, and missed monthly dosages. Decreasing the site shipment shrinkage to 5-10% had the largest impact on warehouse cycle service level because of the extra ordering required at the sites. An increase in daily patient arrivals resulted in the largest improvement in inventory levels for the warehouse and site, but had an extremely negative impact on service levels and missed monthly dosages. This means that excess unplanned demand will lower costs associated with holding inventory, but is undesirable from a consistent patient care perspective. Increasing the probability that an order is placed at the site level yielded the biggest improvement in administering site cycle service level (improvement from baseline =

5.8%). This scenario led to the highest improvement in missed monthly patient dosages. See table 13.

Table 9: Output Summary – Warehouse Cycle Service Level Improvement

Scenario	Warehouse Cycle Service Level	Improvement from Baseline
Baseline	93.8%	0.0%
Site Demand Increase (μ = 30 patient/day)	91.0%	-2.7%
Site Order Efficiency (95%)	94.1%	0.4%
Site Order Efficiency (99%)	94.9%	1.1%
Site Lead-Time Variability Decrease (σ = 3.5 days)	94.8%	1.1%
Warehouse Shipment Shrinkage (5-10%)	95.6%	1.8%
Warehouse Shipment Shrinkage (5-15%)	94.8%	1.1%
Site Shipment Shrinkage (5-10%)	96.3%	2.5%
Site Shipment Shrinkage (5-15%)	95.2%	1.4%

Table 10: Output Summary – Warehouse Avg. Inventory Level % Improvement

Scenario	Warehouse Avg. Inventory Level	% Improvement from Baseline
Baseline	2,967	0%
Site Demand Increase (μ = 30 patient/day)	2,668	10%
Site Order Efficiency (95%)	2,801	6%
Site Order Efficiency (99%)	2,751	7%
Site Lead-Time Variability Decrease (σ = 3.5 days)	2,927	1%
Warehouse Shipment Shrinkage (5-10%)	3,216	-8%
Warehouse Shipment Shrinkage (5-15%)	3,095	-4%
Site Shipment Shrinkage (5-10%)	3,368	-14%
Site Shipment Shrinkage (5-15%)	2,945	1%

Table 11: Output Summary –Site Cycle Service Level Improvement

Scenario	Site Cycle Service Level	Improvement from Baseline
Baseline	84.9%	0.0%
Site Demand Increase (μ = 30 patient/day)	75.8%	-9.2%
Site Order Efficiency (95%)	89.6%	4.7%
Site Order Efficiency (99%)	90.8%	5.8%
Site Lead-Time Variability Decrease (σ = 3.5 days)	86.5%	1.6%
Warehouse Shipment Shrinkage (5-10%)	89.7%	4.8%
Warehouse Shipment Shrinkage (5-15%)	88.7%	3.7%
Site Shipment Shrinkage (5-10%)	90.0%	5.1%
Site Shipment Shrinkage (5-15%)	88.5%	3.5%

Table 12: Output Summary – Site Avg. Inventory Level % Improvement

Scenario	Site Avg. Inventory Level	% Improvement from Baseline
Baseline	997	0.0%
Site Demand Increase (μ = 30 patient/day)	818	17.9%
Site Order Efficiency (95%)	1,029	-3.2%
Site Order Efficiency (99%)	1,048	-5.1%
Site Lead-Time Variability Decrease (σ = 3.5 days)	1,050	-5.3%
Warehouse Shipment Shrinkage (5-10%)	1,086	-9.0%
Warehouse Shipment Shrinkage (5-15%)	1,082	-8.6%
Site Shipment Shrinkage (5-10%)	1,139	-14.3%
Site Shipment Shrinkage (5-15%)	1,081	-8.4%

Table 13: Output Summary – Total Missed Monthly Dosage % Improvement

Scenario	Missed Monthly Dosages	% Improvement from Baseline
Baseline	8,216	0.0%
Site Demand Increase (μ = 30 patient/day)	15,644	-90.4%
Site Order Efficiency (95%)	5,629	31.5%
Site Order Efficiency (99%)	5,023	38.9%
Site Lead-Time Variability Decrease (σ = 3.5 days)	7,314	11.0%
Warehouse Shipment Shrinkage (5-10%)	5,552	32.4%
Warehouse Shipment Shrinkage (5-15%)	6,135	25.3%
Site Shipment Shrinkage (5-10%)	5,389	34.4%
Site Shipment Shrinkage (5-15%)	6,230	24.2%

6.6 Implementing the Model

The purpose of this model to help countries and nonprofit organizations gain deeper insights into their supply chain operations. The simulation was constructed in Microsoft Excel in order to increase the likelihood of use and adoption. Baseline data, e.g., number of suppliers and sites, treatment demand, lead-times, shrinkage, etc., can be adjusted to represent a country's specific operating landscape. Countries before implementing HIV/AIDS policy changes should analyze how these initiatives will affect the entire system, both upstream and downstream. In attempts to be cost-effective, organizations should pursue operational improvements that will yield the most significant benefits given capital expenditure. As expected, some parameter changes had a larger impact on performance measurements than others. See *Results Summary* section.

The most important take away from this model is realizing how situations unique to the HIV/AIDS supply chain in developing countries affect service levels in the entire system, *Baseline Comparison* scenario 1. Because of complexities such as shrinkage and order placement probability, warehouse cycle service levels were on average 6% and sites 14% lower than theoretical values. Organizations will need to either invest in measures that will minimize inherent issues or design policies, e.g., higher order-up-to

levels, which will account for these complexities. Lowering the incident of missed patient dosages is critical in eradicating HIV/AIDS in the long-run. There is a clear trade-off between inventory and cycle service levels. The impact of poor service levels or missed patient dosages may not be evident in the short-run, but the long-run ramifications are enormous. Fortunately, as the price of treatments goes down, purchasing and holding inventory will become less of a financial burden.

7 Opportunities for Further Research

There are additional research opportunities. A few logical extension areas are treatment demand fluctuation, location additions, national fixed-ordering policy changes, and HIV/AIDS eradiation from a systems dynamic perspective. Continual research effort in HIV/AIDS will help deter the spread of disease and disease related deaths.

Patient treatment adherence is an issue that was not incorporated into the model. It was assumed that all patients arrive to the sites monthly for their ARV drugs and receive prescriptions given product availability. It is more likely, that some subset of the patient population will not return for treatment based on the issues mentioned previously, e.g., lack of food and water, transportation, education, etc. The incident of missed treatment dosages will increase with lower levels of patient adherence. Countries should work to understand how improving consumer behavior will impact quality patient care.

Furthermore, the model only considers one warehouse and two treatment sites. It makes sense to include additional locations in order to gain a more expansive understanding of the system. All facilities, upstream and downstream, should be added to the model. As can be seen in the *Results Summary* section, decisions in one node affect performance measurements in other locations. Countries can make better informed logistics decisions if the model is modified to accurately represent their current distribution network.

Additionally, work can be done in understanding the impact of an annual national ordering policy with fixed delivery shipments. A major research assumption is that delivery quantities arriving in country can be changed based on current inventory levels.

This may not be a reasonable option. Operating bureaucracy may force countries to determine scheduled delivery amounts at the beginning of the year. Slight alternations to the model will allow it to be used from a different perspective. In the simulation runs in chapter 6, patient demand dictated order-up-to-levels and order quantities. If shipment amounts are now fixed, the model can help determine the number of patients that can be served without sacrificing high cycle service levels.

Lastly, the threat of widespread resistance can be explored further through modeling techniques. As the influx of funding for HIV/AIDS initiatives continues, organization should work to match short-run tactical goals with long-run desired outcomes. The end objective is to eradicate HIV/AIDS. Countries need to understand how operational decisions today impact the end objective, especially because HIV/AIDS is a biologically adaptive and patients must commit to life-long therapies. A systems dynamic approach can be utilized to synchronize immediate decision-making processes with long-term objectives. Countries and nonprofit organizations today should work to properly focus resource investments in order to build a sustainable HIV/AIDS strategy.

8 Conclusion

As generous funding efforts continue, nonprofit organizations and governments must ensure that these financial resources are allocated effectively and appropriately. This research explores one avenue for improvement, supply chain optimization. Countries can make immediate improvements in operations by understanding the problems that plague their systems. According to the baseline data used in the simulation model, warehouse service levels were 4% lower than theoretical values because of system complexities, and site service lagged by about 14%. Excess unplanned demand lowered inventory levels, but yielded the largest negative impact on service levels. Decreases in site shipment shrinkage and order inefficiencies resulted in significant improvements in missed patient dosages. Countries can greatly improve performance measures by managing demand, recruiting and training resources, decreasing lead-time variability, and lowering shrinkage rates.

Admittedly, there are many pressing needs in the world, but HIV/AIDS is a major hurdle for impoverished nations to overcome in establishing a stable economy. An economy cannot be developed without the valuable contribution of its constituents. Thankfully, HIV/AIDS is no longer a life-terminating illness, but unfortunately critical treatments are not reaching those infected because of poor healthcare infrastructures. Healthcare is a basic human right. A properly designed supply chain can help improve patient care and provide people in the developing world with the essential resources to lead long healthy lives: drug treatment, nutrition, and education.

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Appendix I: Acronyms

ARV	Antiretroviral
CDC	Center for Disease Control
CHAI	Clinton Foundation HIV/AIDS Initiative
CSHOR	Consortium for Strategic HIV Operations Research
CSL	Cycle Service Level
GAP	CDC Global AIDS Program
HAART	Highly Active Retroviral Therapy
KEMSA	Kenya Medical Supplies Agency
MIPH	Management of International Public Health
MSF	Medecins Sans Frontieres
NMS	National Medical Stores in Entebbe
NGO	Non-Government Organizations
NNRTIs	Non-Nucleoside Reverse Transcriptase Inhibitors
NRTIs	Nucleoside/Nucleotide Reverse Transcriptase Inhibitors
PEPFAR	President's Emergency Plan for Aids Relief
PIs	Protease Inhibitors
SMDP	Sustainable Management and Development Program
UN	United Nations
WHO	World Health Organization

Appendix II: Sub-Saharan Africa Procurement

Table 14: Sub-Saharan Africa ARV Drug Consignee Data – 2004 to 2006

Consignee Name	Number of Units	Percentage
ACCONDA	1126032	0.04%
ACONDA/MTCT	1827246	0.07%
AIDS Relief ART Project	12084400	0.44%
Artsen zonder Grenzen	23280	0.00%
CABINET DU PREMIER MINISTRE COORDINATION INTERSECTORIELLE	33810	0.00%
CABINET DU PREMIER MINISTRE COORDINATION INTERSECTORIELLE DE	1139700	0.04%
CAMEG	2298000	0.08%
CAMEROON BAPTIST CONVENTION C/O EUROPEAN BAPTIST GUEST HOUSE	6720	0.00%
CENAMES	101010	0.00%
Centrale Pharmaceutique	555000	0.02%
Centre régional de recherche	132900	0.00%
CIDRZ P.O. BOX 34681	44202626	1.60%
Clinton HIV/AIDS Initiative	89016	0.00%
COMITE NATIONAL DE LUTTE CONTRE LE GUINEA	1390552	0.05%
COMMUNITY OF SAINT EGIDIO/ DREAM PROGRAM MALAWI	15600	0.00%
Conseil National de Lutte	7502530	0.27%
Croix-Rouge Francaise	1846500	0.07%
Deutsche Gesellschaft fuer	1694610	0.06%
Elizabeth Glaser Pediatric	4538400	0.16%
ETHEKWINI PHARMACY SUPPLIES 164 DAWNWEST CRESCENT	675934	0.02%
Harvard School of Public	32874030	1.19%
Hôpital Adventist de Béré	222360	0.01%
IKHWEZI LOKUSA WELLNESS CENTER	598080	0.02%
Instit. Marques de Valle Flor	38640	0.00%
International Rescue Committee	84380	0.00%
John Snow Inc.	25071870	0.91%
Lifeline Malawi Association	63000	0.00%
Management Sciences for Health	97925086	3.54%
Medimoc, Sarl	9141830	0.33%
MEDS	2417850	0.09%
MINISTERE CHARGE DE LA PLANIFICATION ET DU DEVELOPMENT	653310	0.02%
MINISTERE DE LA SANTE PUBLIQUE	3860010	0.14%
Ministry of Health	127837028	4.62%
MINISTRY OF HEALTH - KENYA MEDICAL SUPPLIES AGENCY (KEMSA)	3163020	0.11%
MINISTRY OF HEALTH HEALTH GENERAL DIRECTOR	1251540	0.05%
MINISTRY OF HEALTH PHARMACEUTICALS	57629200	2.08%
Missionpharma	20596860	0.74%
National AIDS Secretariat	700980	0.03%
National Drug Service	18054460	0.65%
NATIONAL DRUG SERVICE ORGANIZATION	1121580	0.04%
NATIONAL PHARMACEUTICAL COMPANY (NATPHARM)	5121300	0.19%
Nederlands Handelshuis Zuid	186750	0.01%
ORGANISATION MONDIALE DE LA SANTE CAMAYENNE, CORNICHE NORD	8100	0.00%
PASS	11075600	0.40%
PERINATAL HIV RESEARCH UNIT CHRIS HANI BARAGWANATH HOSPITAL	1221024	0.04%
Pharmacie Centrale de Guinee	209580	0.01%
PHARMACIE DE LA SANTE PUBLIQUE (PSP KM 4 BOULEVARD DE MARSEILLE	13447080	0.49%
PHARMACIE DE LA SANTE PUBLIQUE DE COTE D'IVOIRE	252420	0.01%
Pharmacie Nationale	2472200	0.09%
PHARMID	45603856	1.65%
Programme National Multisector	2562240	0.09%
Project Management Unit	747990	0.03%
Swiss AIDS Care	120000	0.00%
The Director General	108000	0.00%
THE NATIONAL AIDS SECRETARIAT GOVERNMENT OF THE GAMBIA	17100	0.00%
UMKHUMBANE CLINIC PHARMACY KALLENDEN ROAD	615030	0.02%
UNDP	92111882	3.33%
UNICEF	132631922	4.79%
University of Maryland	50493062	1.82%
Ve'ahavta	186840	0.01%
WHO/OMS	11979284	0.43%
WORLDWIDE ORPHANS FOUNDATION, ETHIOPIA	140640	0.01%
Other	1911188694	69.07%
Grand Total	2767089574	

Table 15: 2006 Sub-Saharan Africa Country of Manufacturer Data – ARV Drugs

Country of Manufacture	Number of Units	Percentage
Australia	1380300	0.0%
Canada	33517980	1.2%
Costa Rica	570	0.0%
Denmark	592520	0.0%
France	60988726	2.2%
Germany	68399319	2.5%
Greece	5097120	0.2%
India	893297830	32.3%
Iraq	14000	0.0%
Ireland	246000	0.0%
Kenya	1783798	0.1%
Mexico	42480	0.0%
Namibia	195600	0.0%
Netherlands	50056677	1.8%
Russian Federation	202500	0.0%
Samoa	20700	0.0%
Solomon Islands	2400	0.0%
South Africa	95556428	3.5%
Spain	1893030	0.1%
Switzerland	25516584	0.9%
Uganda	80718	0.0%
United Kingdom of Great Britain and Northern Ireland	93747382	3.4%
United States of America	50912125	1.8%
Other	1383544787	50.0%
Grand Total	2767089574	100.0%

Table 16: 2006 Sub-Saharan Africa ARV Drug Manufacturer Data – 2004 to 2006

Manufacturer	Number of Units	Percentage
A to Z Textiles Limited	2574210	0.09%
Abbott Laboratories Ltd.	14283118	0.52%
Aspen Pharmacare	5765040	0.21%
Aspen Pharmacare Ltd.	71254790	2.58%
Aurobindo Ltd.	189293999	6.84%
Boehringer Ingelheim	89690919	3.24%
Bristol-Myers Squibb	78353761	2.83%
Cadila	240000	0.01%
Cipla Ltd.	530496763	19.17%
Emcure	33168200	1.20%
Geka Pharma	195600	0.01%
Gilead Sciences Inc.	529830	0.02%
Gilead Sciences, Inc.	3299490	0.12%
GlaxoSmithKline Ltd.	121202502	4.38%
Hetero Drugs Ltd.	65697580	2.37%
Hoffman La Roche	30897198	1.12%
IDA	12272000	0.44%
IHD	532800	0.02%
Merck, Sharp & Dohme Ltd.	54836157	1.98%
Meymac	600	0.00%
Patheon	122220	0.00%
Ranbaxy Ltd.	40918190	1.48%
Ranbaxy Ltd..	399000	0.01%
Roxane Laboratories	72000	0.00%
Roxanne Lab.	6224400	0.22%
Star Pharmaceuticals Ltd.	600	0.00%
Strides Arcolab Ltd.	31128180	1.12%
To be verified	54000	0.00%
UNICEF Warehouse	41640	0.00%
Other	1383544787	50.00%
Grand Total	2767089574	

Table 17: Sub-Saharan ARV Drug Purchasing Volumes – 2004 to 2006

Country	Number of Units	Percentage
Angola	19863362	0.72%
Benin	11724820	0.42%
Burkina Faso	11751742	0.42%
Burundi	9400950	0.34%
Cameroon	2609940	0.09%
Cape Verde	1251540	0.05%
Central African Republic	19707898	0.71%
Chad	777360	0.03%
Congo	1333140	0.05%
Côte d'Ivoire	45019890	1.63%
Democratic Republic of the Congo	20832184	0.75%
Equatorial Guinea	752872	0.03%
Eritrea	747990	0.03%
Ethiopia	225935702	8.17%
Gabon	3373470	0.12%
Gambia	1073682	0.04%
Ghana	26370420	0.95%
Guinea	7418168	0.27%
Guinea-Bissau	2264400	0.08%
Kenya	51431398	1.86%
Lesotho	20697520	0.75%
Liberia	3114210	0.11%
Madagascar	118950	0.00%
Malawi	63234096	2.29%
Mali	8789511	0.32%
Mauritania	434070	0.02%
Mozambique	36482849	1.32%
Namibia	75142610	2.72%
Niger	1388610	0.05%
Nigeria	105339010	3.81%
Rwanda	20988175	0.76%
Sao Tome and Principe	38640	0.00%
Senegal	4427170	0.16%
Seychelles	46612	0.00%
Sierra Leone	1693600	0.06%
Somalia	29940	0.00%
South Africa	103359992	3.74%
Sudan	4252688	0.15%
Swaziland	42436334	1.53%
Togo	15564600	0.56%
Uganda	66482176	2.40%
United Republic of Tanzania	152716788	5.52%
Zambia	182531426	6.60%
Zimbabwe	10594282	0.38%
Grand Total	2767089574	

Appendix III: Order-Up-To Calculations

Table 18: Warehouse Order-Up-To Calculations (CSL = 99.99%)

INVENTORY POLICY CALCULATIONS FOR WAREHOUSE	
Cycle Service Level	100%
Safety Stock Factor (k)	3.72
Annual Demand (units)	18000
Expected Lead Time (days)	42
STD Lead Time (days)	14
Review Period (days)	90
Expected Daily Demand (units)	50.0
STD Daily Demand (units)	7.1
Max-Level or S (units) =	**9130**
Expected Lead Time + Review Period Demand (units)	6510
STD Lead Time Demand (units)	704.7

Table 19: Site Order-Up-To Calculations (CSL = 99.99%)

INVENTORY POLICY CALCULATIONS FOR EACH SITE (2)	
Cycle Service Level	100.0%
Safety Stock Factor (k)	3.72
Annual Demand (units)	9000
Expected Lead Time (days)	35
STD Lead Time (days)	7
Review Period (days)	60
Expected Daily Demand (units)	25.0
STD Daily Demand (units)	5.0
Max-Level or S (units) =	**3018**
Expected Lead Time + Review Period Demand (units)	2342
STD Lead Time Demand (units)	181.7

*Yellow highlight indicates input value cells

Appendix IV: Simulation Model

Number of Suppliers	3
Supplier Mean LT (days) =	42
Supplier STD LT (days) =	14
Mean LT - DC to sites (days) =	35
STD LT - DC to sites (days) =	7
Mean Patient (# patients /day) =	25
STD Patient (# patients / day) =	5.0
Total Monthly Patients (A) =	750
Total Monthly Patients (B) =	750

	Order Probability			1- Shrinkage (%)	INV. Levels (mnths of supply)	INV. Levels (units)
Distribution	N/A	N/A	Min	80	10.0	15000
	N/A	N/A	Max	95	10.0	15000
Site A	0	10%	Min	80	8.0	6000
	1	90%	Max	95	8.0	6000
Site B	0	10%	Min	80	8.0	6000
	1	90%	Max	95	8.0	6000

Year	Month	DC Request	Instransit Supplier 1	Days to Arrive 1	Ship Arrival 1	Instransit Supplier 2	Days to Arrive 2	Ship Arrival 2	Instransit Supplier 3	Days to Arrive 3	Ship Arrival 3	DC INV BEG	Stockout?
	0											15000	0
1	1		0	0		0	0		0	0		15000	0
1	1	117	32	35	0	35	47	0	37	46	0	14883	0
1	1		32	34	0	35	46	0	37	45	0	14883	0
1	1		32	33	0	35	45	0	37	44	0	14883	0
1	1		32	32	0	35	44	0	37	43	0	14883	0
1	1		32	31	0	35	43	0	37	42	0	14883	0
1	1		32	30	0	35	42	0	37	41	0	14883	0
1	1		32	29	0	35	41	0	37	40	0	14883	0
1	1		32	28	0	35	40	0	37	39	0	14883	0

Figure 14: Model Input and Screen Shot Illustration

*Yellow highlight indicates input value cells

Appendix V: Simulation Runs

Table 20: Baseline Comparison Simulation Runs

Safety Stock Factor = 3.72 (Theoretical CSL = 99.99%)	DC CSL	DC AVG INV	SITE CSL	SITE AVG INV	MISSED
Run 1	92.69%	2,723	84.34%	1025	8622
Run 2	93.61%	3,037	87.58%	1058	6858
Run 3	95.07%	2,772	84.98%	1008	8081
Run 4	93.33%	2,983	86.53%	1111	7423
Run 5	96.71%	3,035	84.98%	903	8164
Run 6	94.79%	2,989	85.98%	1045	7613
Run 7	99.18%	3,122	85.94%	990	7533
Run 8	91.14%	2,971	86.99%	953	7186
Run 9	89.04%	2,490	83.38%	954	9051
Run 10	92.33%	3,549	78.49%	919	11629
Average	**93.79%**	**2,967**	**84.92%**	**997**	**8,216**
Safety Stock Factor = 2.05 (Theoretical CSL = 98%)	**DC CSL**	**DC AVG INV**	**SITE CSL**	**SITE AVG INV**	**MISSED**
Run 1	92.51%	2,495	83%	856	9,399
Run 2	89.50%	2,144	79%	745	11,262
Run 3	88.86%	1,866	81%	718	9,875
Run 4	93.52%	2,149	86%	813	7,379
Run 5	88.58%	2,000	83%	824	9,347
Run 6	91.05%	2,549	84%	799	8,494
Run 7	96.26%	2,303	83%	802	9,090
Run 8	97.26%	2,824	81%	851	10,773
Run 9	92.79%	2,121	97%	902	1,620
Run 10	91.51%	2,243	80%	804	11,253
Average	**92.18%**	**2,269**	**83.65%**	**811**	**8,849**
Safety Stock Factor = 1.75 (Theoretical CSL = 96%)	**DC CSL**	**DC AVG INV**	**SITE CSL**	**SITE AVG INV**	**MISSED**
Run 1	90.23%	2,140	77%	705	12,876
Run 2	94.34%	2,553	80%	749	10,681
Run 3	95.34%	2,103	82%	825	9,952
Run 4	89.32%	2,073	76%	692	12,963
Run 5	89.04%	2,040	88%	883	6,581
Run 6	93.24%	2,472	83%	752	9,095
Run 7	91.87%	2,193	86%	772	7,292
Run 8	88.49%	2,718	74%	707	14,204
Run 9	96.89%	2,397	83%	803	9,193
Run 10	85.39%	2,437	75%	668	13,447
Average	**91.42%**	**2,313**	**80.36%**	**756**	**10,628**
Safety Stock Factor = 1.55 (Theoretical CSL = 94%)	**DC CSL**	**DC AVG INV**	**SITE CSL**	**SITE AVG INV**	**MISSED**
Run 1	91.32%	1,989	74%	587	14,059
Run 2	93.33%	2,066	80%	650	10,952
Run 3	86.12%	1,805	84%	819	8,518
Run 4	87.21%	1,906	81%	711	10,648
Run 5	93.70%	1,932	86%	752	7,723
Run 6	91.23%	1,939	86%	852	7,408
Run 7	88.86%	1,969	76%	689	13,095
Run 8	95.07%	2,074	79%	709	11,525
Run 9	95.98%	1,914	77%	684	12,296
Run 10	87.40%	2,105	71%	652	15,599
Average	**91.02%**	**1,970**	**79.32%**	**711**	**11,182**

Table 20 continued…

Safety Stock Factor = 1.41 (Theoretical CSL = 92%)	DC CSL	DC AVG INV	SITE CSL	SITE AVG INV	MISSED
Run 1	87.03%	2,263	79%	730	11,302
Run 2	88.58%	2,040	75%	658	14,027
Run 3	93.88%	1,838	69%	659	16,569
Run 4	89.86%	1,939	86%	774	7,887
Run 5	86.58%	1,824	76%	702	12,647
Run 6	90.68%	1,841	79%	724	11,590
Run 7	86.76%	2,195	75%	775	13,407
Run 8	87.03%	1,778	83%	693	9,458
Run 9	87.03%	2,126	74%	784	14,128
Run 10	91.60%	2,222	77%	691	12,073
Average	**88.90%**	**2,007**	**77.23%**	**719**	**12,309**
Safety Stock Factor = 1.28 (Theoretical CSL = 90%)	**DC CSL**	**DC AVG INV**	**SITE CSL**	**SITE AVG INV**	**MISSED**
Run 1	91.14%	2,505	78%	756	11,786
Run 2	93.06%	1,923	79%	709	11,577
Run 3	87.40%	2,044	70%	665	16,330
Run 4	86.39%	1,844	76%	745	13,069
Run 5	88.95%	1,889	81%	763	10,171
Run 6	78.81%	1,898	77%	688	12,239
Run 7	85.94%	1,981	83%	700	8,846
Run 8	78.36%	1,891	83%	666	9,270
Run 9	91.14%	2,236	73%	708	14,193
Run 10	95.43%	1,918	78%	762	12,070
Average	**87.66%**	**2,013**	**77.82%**	**716**	**11,955**

Table 21: Increased Patient Demand Simulation Runs

Mean Patient Arrival = 30 (patients/day)	DC CSL	DC AVG INV	SITE CSL	SITE AVG INV	MISSED
Run 1	96.62%	2,789	79%	828	13,767
Run 2	90.05%	2,364	78%	871	14,044
Run 3	89.68%	2,500	75%	782	16,312
Run 4	87.21%	2,376	74%	802	16,956
Run 5	90.96%	2,788	81%	863	12,474
Run 6	92.33%	3,140	74%	840	16,450
Run 7	92.69%	3,113	70%	745	19,663
Run 8	91.42%	2,671	76%	848	15,593
Run 9	86.67%	2,377	73%	861	17,564
Run 10	92.79%	2,565	79%	744	13,613
Average	**91.04%**	**2,668**	**75.76%**	**818**	**15,644**

Table 22: Increased Site Order Efficiency Simulation Runs

Order Placement Probability = 95%	DC CSL	DC AVG INV	SITE CSL	SITE AVG INV	MISSED
Run 1	90.96%	2,475	91%	1,043	4,662
Run 2	93.42%	2,763	91%	999	4,934
Run 3	97.72%	2,828	83%	897	8,866
Run 4	93.79%	3,259	90%	1,146	5,213
Run 5	94.52%	3,158	87%	950	7,188
Run 6	95.71%	2,768	95%	1,114	2,804
Run 7	93.33%	2,658	90%	1,112	5,201
Run 8	91.32%	2,738	87%	970	7,139
Run 9	92.15%	2,546	89%	993	6,104
Run 10	98.54%	2,818	92%	1,065	4,176
Average	**94.15%**	**2,801**	**89.57%**	**1,029**	**5,629**
Order Placement Probability = 99%	**DC CSL**	**DC AVG INV**	**SITE CSL**	**SITE AVG INV**	**MISSED**
Run 1	95.07%	2,634	82%	924	9,783
Run 2	99.63%	2,956	96%	1,132	2,209
Run 3	98.36%	2,442	93%	1,093	3,862
Run 4	89.77%	2,721	92%	1,031	4,467
Run 5	95.16%	2,816	94%	1,070	3,374
Run 6	93.42%	2,504	95%	1,083	2,842
Run 7	89.13%	2,694	82%	909	9,646
Run 8	94.06%	3,579	90%	1,051	5,503
Run 9	95.25%	2,696	86%	997	7,720
Run 10	99.45%	2,467	98%	1,191	826
Average	**94.93%**	**2,751**	**90.76%**	**1,048**	**5,023**

Table 23: Decreased Site Lead-Time Variability Simulation Runs

Site Lead-Time Mean = 35 days, Std. Dev. = 3.5 days	DC CSL	DC AVG INV	SITE CSL	SITE AVG INV	MISSED
Run 1	97.63%	2,973	91%	1,141	4,970
Run 2	96.26%	2,817	92%	1,144	4,273
Run 3	91.78%	2,568	84%	1,052	8,627
Run 4	99.45%	3,174	91%	1,125	4,526
Run 5	92.69%	2,898	84%	1,039	8,927
Run 6	95.62%	3,560	83%	1,030	9,012
Run 7	96.26%	3,126	89%	998	6,182
Run 8	91.23%	2,349	87%	999	7,154
Run 9	97.63%	3,323	87%	1,023	6,806
Run 10	89.95%	2,484	77%	949	12,664
Average	**94.85%**	**2,927**	**86.53%**	**1,050**	**7,314**

Table 24: Decreased Warehouse Shipment Shrinkage Simulation Runs

Shrinkage = 5-15%	DC CSL	DC AVG INV	SITE CSL	SITE AVG INV	MISSED
Run 1	95.43%	3,093	91%	1,083	4,990
Run 2	96.53%	3,074	83%	1,058	9,028
Run 3	98.45%	3,296	89%	1,077	6,068
Run 4	87.31%	2,771	84%	949	8,891
Run 5	98.72%	2,452	93%	1,145	3,780
Run 6	91.78%	3,015	91%	1,113	5,065
Run 7	90.50%	2,740	94%	1,126	3,229
Run 8	98.63%	2,731	98%	1,278	1,070
Run 9	92.42%	3,723	83%	942	9,249
Run 10	98.63%	4,050	82%	1,052	9,976
Average	**94.84%**	**3,095**	**88.66%**	**1,082**	**6,135**
Shrinkage = 5-10%	**DC CSL**	**DC AVG INV**	**SITE CSL**	**SITE AVG INV**	**MISSED**
Run 1	96.16%	3,545	87%	1,026	6,809
Run 2	92.97%	2,778	91%	1,121	4,576
Run 3	88.04%	2,993	82%	903	9,912
Run 4	91.78%	3,111	89%	1,036	6,313
Run 5	99.82%	3,221	93%	1,193	3,711
Run 6	96.99%	3,527	87%	1,134	7,111
Run 7	98.90%	3,100	93%	1,132	3,952
Run 8	96.16%	3,529	90%	1,111	5,196
Run 9	97.35%	3,407	89%	1,054	5,699
Run 10	97.90%	2,947	96%	1,150	2,235
Average	**95.61%**	**3,216**	**89.74%**	**1,086**	**5,552**

Table 25: Decreased Site Shipment Shrinkage Simulation Runsuns

Shrinkage = 5-15%	DC CSL	DC AVG INV	SITE CSL	SITE AVG INV	MISSED
Run 1	91.51%	3,045	85%	1,023	7,938
Run 2	91.42%	2,517	80%	1,048	10,918
Run 3	95.53%	2,699	94%	1,144	3,365
Run 4	98.17%	3,002	87%	1,024	6,859
Run 5	93.15%	2,570	91%	1,104	5,019
Run 6	91.78%	3,380	89%	1,119	6,244
Run 7	96.99%	2,952	93%	1,082	3,834
Run 8	98.17%	2,938	95%	1,168	2,900
Run 9	96.35%	3,156	85%	1,017	8,194
Run 10	99.00%	3,195	87%	1,080	7,027
Average	**95.21%**	**2,945**	**88.46%**	**1,081**	**6,230**
Shrinkage = 5-10%	**DC CSL**	**DC AVG INV**	**SITE CSL**	**SITE AVG INV**	**MISSED**
Run 1	99.18%	3,818	84%	1,090	8,444
Run 2	98.17%	3,581	92%	1,173	4,412
Run 3	92.60%	3,372	88%	1,102	6,685
Run 4	98.08%	3,248	94%	1,243	3,111
Run 5	97.99%	3,326	94%	1,199	3,168
Run 6	93.33%	3,223	91%	1,107	4,914
Run 7	97.17%	3,383	89%	1,082	5,988
Run 8	89.41%	2,955	88%	1,081	6,484
Run 9	99.18%	3,409	92%	1,231	4,164
Run 10	97.90%	3,369	88%	1,086	6,525
Average	**96.30%**	**3,368**	**89.99%**	**1,139**	**5,389**