Abstract

Murray, Talisa Marie. Examining Intervention Schemes through Simulation Modeling to Improve Access to Colorectal Cancer Care (Dr. Stephen Roberts and Dr. Yahya Fathi, Co-Chairs)

Colorectal cancer, commonly referred to as colon cancer, has a major impact on the US population today. Even though there are preventative measures, such as screening for developing disease, only a small percentage of the US population takes advantage of screening methods. There are a number of barriers in seeking screening. This thesis addresses the barriers that exist in accessing colon cancer care and uses simulation modeling to examine the effectiveness of various intervention schemes in improving screening rates for the North Carolina population.

Arena v. 7.0, a simulation modeling language created by Rockwell Software, was used to simulate the colon cancer system. The system was modeled using a combined discrete-continuous model since there are discrete and continuous components within the system. The dynamics among the components was investigated and modeled. The four major sectors of the model were: the health care delivery system, the role of the patient, the role of the physician, and the socioeconomic state of the system.

Intervention schemes were incorporated in the model to capture "realistic" mechanisms. Data from many sources (primarily for North Carolina) were used to obtain numerical values for the mechanisms. There were four intervention categories that were examined in this study: improvement in resource capacity, patient adherence intervention, physician intervention, and multimedia intervention. Each simulation trial run time was 1095 days (3 years), and each trial generated the results for the performance measures, which were the basis for examining the effectiveness of the intervention schemes. The

performance measures included the awareness level, the demand level, the screening level, and the screening rate.

Analysis was performed and results showed that intervention schemes that improved the awareness level were most effective in increasing the overall screening level. In addition, results showed that combining all of the intervention schemes can be very powerful and produce very high screening levels. Overall, this study provided enlightenment in how beneficial intervention schemes are and to some extent, hope that the burden of colon cancer on the US population can be alleviated.

EXAMINING INTERVENTION SCHEMES THROUGH SIMULATION MODELING TO IMPROVE ACCESS TO COLORECTAL CANCER CARE

by

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Biography

Talisa Murray was born in Los Angeles, CA and raised in Silver Spring, MD. She is the daughter of Dr. Gareth and Diane Murray, and sister of Gareth Murray, Jr. Ms. Murray received her Bachelor of Science degree with high honors, in Mathematics, from Spelman College in May of 2001. Her undergraduate academic achievements include memberships in Phi Beta Kappa and Pi Mu Epsilon National Honor Societies. While pursuing her graduate studies at North Carolina State University, she was inducted into the Omega Rho International Honor Society. Ms. Murray will be receiving her Master of Science Degree in Operations Research and Industrial Engineering in December of 2004.

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Table of Contents

List of Tables

List of Figures

1 INTRODUCTION

Colorectal cancer, also commonly referred to as colon cancer, has a great impact on the US population today, as it is the third most common type of cancer diagnosed amongst the US population, and the second leading cause of death due to cancer in the US (American Cancer Society 2004b;National Cancer Institute 2002). Although colon cancer is often fatal, early detection, including screening and surveillance tests, can prevent it. However, in general, the awareness of the significance of colon cancer and the knowledge about available preventative measures that one can take is relatively low.

Lack of awareness is just one of the many barriers to colon cancer screening, and care in general that are lurking in US society. Some of the other barriers include a lack of health insurance, the presence of fear and other emotional barriers, and a lack of communication between health care providers and the patient. Furthermore, not only does each barrier have its own role in hindering access to colon cancer screening, but many of the interactions among the various barriers create additional difficulty in accessing colon cancer prevention, detection, and care.

Moreover, a reasonable question to be asked is how can these barriers be overcome? The focus of this thesis is to answer this question and to use the tool of simulation modeling to examine intervention schemes that will reduce, and ideally, eliminate the various factors that hinder access to optimal colon cancer care, and more specifically within the North Carolina population. Simulation is the modeling tool of choice simply because this problem calls for a complex dynamic system. Simulation facilitates the ability to model the colon cancer care system on a large scale and study the effects of the associated changes on a very detailed level, while offering a flexible, reliable, and inexpensive means to do so.

The second chapter of this thesis gives an overview of colon cancer, including the nature of the disease, and what risk factors are associated with it. Then, the importance of preventative measures is addressed and how they are not utilized by a large percentage of the US population, partly due to the lack of access to the preventative care.

Chapter three explains the components of the system used to represent the various factors and their interactions which serve as barriers. More specifically, the relationships reflecting the causes and effects of the different factors are illustrated via a causal loop diagram. Furthermore, in this chapter the system is modeled via simulation. The simulation model is verified to insure the model works as intended. Finally a set of validation tests are performed to show that the model is a credible source of information.

The fourth chapter presents the simulation experiments, the analysis performed, and the corresponding results. The simulation experiments test the effectiveness of different intervention schemes. Some of the intervention schemes include improving the health care delivery system, improving the physician compliance with colon cancer screening guidelines, improving the quality of physician-patient communication, and incorporating social support networks for patient adherence to the screening recommendations.

Finally, this thesis concludes by discussing how barriers to colon cancer care can be eliminated based on the results of the simulation experiments. Some suggestions for further research are also offered.

2 THE NATURE OF COLON CANCER

This chapter introduces the nature of colon cancer and the several risk factors that are associated with colon cancer incidences. It addresses the importance of preventative measures and gives details about the various colon cancer screening tests that are available. In addition, this chapter addresses the low rates for screening and how this occurrence is partly attributed to the existence of colon cancer care barriers.

2.1 What is colon cancer?

It is known that many cases of colon cancer emerge from the growth of tissue within the lining of the colon, known as a polyp. Over the course of several years (sometimes only months), polyps can become cancerous; they begin to grow abnormally and divide uncontrollably, and consequently form a malignant mass or tumor (American Cancer Society 2004d). The cancer can be diagnosed at several stages, which include the local stage, regional stage, and distant stage. The local stage occurs when the cancer is confined to the colon or rectum. The regional stage occurs when the cancer has spread to surrounding tissue, and the distant stage occurs when the cancer has metastasized (American Cancer Society 1999). As with all cancers, if not detected early enough, the cancerous cells metastasize and usually lead to death.

Even though the exact cause of colon cancer is uncertain, there are known risk factors. Some of the factors that increase your risk of colon cancer include a family history of colon cancer, a personal history of colon cancer or polyps, a personal history of bowel disease, and being over 50 years of age, which is the primary risk factor (American Cancer Society 2004c) . Sources say that 90% of colorectal cancer cases are diagnosed in individuals over the age of 50. While those risk factors are for the most part are uncontrollable, some risk factors can be controlled. Such risk factors include diets composed of foods high in fat, a lack of exercise, smoking, being overweight, and high consumption of alcohol (American Cancer Society 2004c). Screening is an important tool to identify people at risk by detecting and removing polyps before cancer develops (Centers for Disease Control 2000).

2.2 The importance in screening for colon cancer

There are colon cancer screening tests that can be performed to detect polyps that could eventually become cancerous, to find cancerous cells at their early stage before they have spread, or to find other abnormalities in the colon (National Cancer Institute 2002). The five most common screening tests for colon cancer are the fecal occult blood test (FOBT), the sigmoidoscopy, the colonoscopy, the double contrast barium enema (DCBE), and the digital rectal examination (DRE) (Centers for Disease Control 2000;National Cancer Institute 2002). The FOBT, which is the least in cost amongst the other tests and the most non-invasive, checks for hidden blood in the stool originating from polyps and colorectal cancer (National Cancer Institute 2002). If blood is detected, a follow-up colonoscopy or DCBE is required (Centers for Disease Control 2000). A sigmoidoscopy examines the rectum and the lower portion of the colon using a lighted instrument referred to as a sigmoidoscope, where as a colonoscopy examines the rectum and the entire colon using a different instrument called a colonoscope (National Cancer Institute 2002). A DCBE provides an alternative means for visualizing the colon via a series of x-rays of the colon (National Cancer Institute 2002). If any polyps are detected, then a follow-up colonoscopy is necessary (Centers for Disease Control 2000). Furthermore, during a DRE, the physician inserts a lubricated, gloved finger into the rectum to feel for any abnormalities. The DRE is limited to the lowest part of the rectum (National Cancer Institute 2002).

According to the American Cancer Society, regular screening should begin for both men and women who are at average risk at age 50. Persons with a family history or other major risk factors should begin screening at age 40. Screening recommendations include having a FOBT and flexible sigmoidoscopy, and if normal, repeating the FOBT annually and the flexible sigmoidoscopy every 5 years; having a colonoscopy, and if normal, repeating every 10 years; or having a DCBE, and if normal, repeating every 5 to 10 years (American Cancer Society 1999). In addition, the DRE should be done prior to the sigmoidoscopy, colonoscopy, or DCBE (American Cancer Society 1999). Should any of the tests find abnormalities, the health care provider will perform a physical exam, evaluate the person's personal and family medical history, may order additional diagnostic tests, and in some cases perform a biopsy to determine if cancer is present

Screening is highly effective in preventing colon cancer, but the percentage of the US population that follows screening recommendations is relatively low. Sources say that approximately 30,000 lives could be saved each year if people would get screenings (2003b). Also, in an earlier National Polyp Study, it has been demonstrated that the removal of polyps from early detection decreased the occurrence of colorectal cancer by 70-90% (SJ Winawer et al. 1993). In addition, the use of screening is believed to be one of the reasons for the decline in the number of colon cancer deaths in the US over the past 15 years, with an average rate of 1.7% per year (American Cancer Society 2003a).

However, there is a lot of room for improvement in the screening rates. According to the American Cancer Society, only approximately 37% of colon cancers are detected at an early stage (Centers for Disease Control 2000). Research has shown that low screening rates are a result of a list of factors that fall into the category of barriers to accessing colon cancer care (American Cancer Society 2002;Reid M.Ness 2001).

2.3 Barriers to accessing colon cancer care

Many reasons for the high incidences of colon cancer relate to the barriers of access to healthcare. It is evident that barriers exist because, while the health care that is available for colon cancer is of high quality and very effective, colon cancer continues to be a major burden on the health of the US population. Colon cancer is the third most common type of cancer diagnosed amongst the US population, and the second leading cause of death due to cancer in the US (American Cancer Society 2004b;National Cancer Institute 2002). The American Cancer society (ACS) projected that 147,500 Americans would be diagnosed with colorectal cancer in 2003, and this disease would cause approximately 57,100 deaths during 2003 (American Cancer Society 2004b). This kind of projection is of major concern and has sparked a large area of interest in the field of public health. Past research discovered that barriers are prominent in both the screening and treatment sectors of colon cancer care.

There are several barriers that hinder people from getting screened for colon cancer. Health insurance and costs, health care delivery, psychological factors, education, culture, and communication all serve as barriers to colon cancer screening. There are high costs associated with screening tests, and the lack of health insurance prevents people from getting screened. According to data retrieved from National Health Interview Survey (NHIS) taking place from January – June of 2003 (RA Cohen and H.Ni 2004), 14.8% of the U.S. population was uninsured at the time of the interview, 18.2% of the U.S. population was uninsured for at least part of the past year, and 9.7% of the U.S. population was uninsured for more than a year. Also, relative to the group of people under the age of 65 (those who do not qualify for Medicare), the NHIS reported that 16.7% were uninsured at the time of the interview, 20.5% were uninsured for at least part of the past year, and 10.9% were uninsured for more than a year. However, even if the patient has health insurance, it is possible that the extent to which the insurance covers the expenses will still result in high out-of-pocket costs. Sometimes this high out-of-pocket cost poses a problem because some people, especially those of lower economic status, are unable to pay the high deductibles (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999). The nature of health care delivery can also serve as a barrier. For example, the lack of screening facilities within a reasonable distance is a hindrance for those people who can afford to get screened (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999). Inconvenient scheduling of the screening procedures is a second example. Difficulties with scheduling an appointment to get screened results in delaying the screening process, or ultimately bypassing the screening process (Reid M.Ness 2001). Primary care shortage is a third example. When there are insufficient primary care physicians, people generally lack a regular source of care, thereby decreasing their chances of getting screened. This behavior tends to be more prominent in rural areas (Georgetown University - Institute for Health Care Research and Policy 2003;National Cancer Policy Board, Institute of

Medicine, and National Research Council 1999;United States General Accounting Office 2003).

Moreover, there are psychological barriers to colon cancer screening. Many times, anxieties about inconvenience, embarrassment, discomfort, and pain involved in screening can deter people from colon cancer screening tests (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999). In addition, cultural or religious beliefs about health care can prevent one from getting screened for colon cancer (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999). Furthermore, a low level of education and awareness of the disease also serve as significant barriers (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999;Reid M.Ness 2001). Studies have clearly illustrated that in general, education has an important role in maintaining a healthy lifestyle (Eric D.High 2004).

However, irrespective of the level of education, many individuals do not know about colon cancer and the benefits of its screening tests. Therefore, there are many cases of colon cancer that are diagnosed at a later stage when it is harder to treat and possibly cure the disease (American Cancer Society 2003a;Centers for Disease Control 2000). There are also language barriers to receiving colon cancer care. For example, Hispanics and some Asian groups have lower screening rates than Whites, or even African Americans on account of their language barrier (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999).

The physician is key when it comes to informing patients about health issues, including colon cancer (American Cancer Society 2003b). One of the strongest indicators that a person will get screened is the receipt of a physician's recommendation to do so (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999). Sources have mentioned that the negligence of physicians in the screening process has hindered people from getting screened (Reid M.Ness 2001). Physicians, overall, request a lower number of cancer screening tests than what is recommended in preventative health care guidelines (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999).

One reason for this behavior is that physicians are usually aware of guidelines, but may not see screening tests as being beneficial without the presence of symptoms (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999). Another reason is that screening guidelines change and physicians may fail to keep up with current standards. A third reason is that many people seek health care only when they are ill, and this decreases the number of opportunities for physicians to address the need for cancer screening tests (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999).

The manner in which the provider communicates to the patient is very important. Researchers have found that the nature of a recommendation for getting screened impacts the patient's compliance with the recommendation (Reid M.Ness 2001). Poor provider-patient communication is also a hindrance to screening. In some cases the wrong information is mistakenly conveyed to the patient, which can lead to serious problems such as the development and progression of colon cancer to advanced stages of the disease as a result of the patient not being ordered to get screened when it was imperative to do so (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999).

It is also important to note that the barriers mentioned above also are considered to be a hindrance for follow-up care after screening, and for treatments. Therefore, these barriers adversely affect colon cancer care as a whole.

The barriers mentioned earlier are considered to be important factors for the development of the simulation model. It is the effect of these factors and their interaction on the access to colon cancer care that will be analyzed later through simulation experiments.

Overall, while colon cancer is a very serious disease and can be fatal, there exist means for preventing much of it. In addition to maintaining good health, undergoing screening and surveillance tests can prevent the development of colon cancer. However, despite the importance of colon cancer screening, the US population in general has difficulty in accessing this type of care partly due to the existence of several barriers. The following chapter addresses the factors associated with the colon cancer care system in the context of the simulation model construction. This simulation model will later be used to analyze the colon cancer care system and to examine different types of interventions in helping to eliminate these barriers.

3 DEVELOPMENT OF THE SIMULATION MODEL

The previous chapter introduced the concept of colon cancer and the many factors serving as barriers to colon cancer care. This chapter introduces the different factors as major components of a systematic model. A systematic approach is used to facilitate the need to capture the dynamics and interactions of the various factors. This chapter illustrates the system dynamics via a causal loop diagram, and later illustrates how the system is represented through simulation modeling, and more specifically, a combined discrete-continuous model.

3.1 Presentation of the System

The system modeled in this study is the interaction of the various factors that serve as barriers to accessing colon cancer care (CCC) in the state of North Carolina. The factors considered include: (1) health care delivery, (2) the role of the physician, (3) socioeconomic status, and (4) the role of the patient. Each factor consists of several underlying interactive variables that govern its total effect on the major performance measure, or the screening rate, which is simply the percentage of individuals amongst the 50 and older population who are getting screened.

3.2 Conceptual Model Development

A causal loop diagram, shown in Figure 3.1, was constructed to obtain a better understanding of the different variables constituting each factor, and how those variables interacted. A causal loop diagram is a useful tool for representing the feedback structure of a system. A causal loop diagram is composed of variables connected by arrows indicating the causal influences among the variables. The arrows symbolize causal links, and the arrows are directed from the cause to the effect. Each causal link is assigned a polarity, either positive (+) or negative (-). A positive link indicates that if the cause increases, the effect increases and if the cause decreases, the effect decreases. On the other hand, a negative link indicates that if the cause increases, the effect decreases, and if the cause decreases, the effect increases (John D.Sterman 2000). As can be seen below in Figure 3.1, a collection of variables represents a factor of the system. Also, Figure 3.1 clearly shows the different variables within each factor and how every variable affects some other variable, and ultimately, the screening rate. This causal loop representation of the system provides a picture of the dynamics of the system and provides the opportunity to create a clearer image of how the system should be modeled in the simulation.

In reference to Figure 3.1, it is apparent that several variables have to be incorporated into the simulation model. More specifically, it is necessary to have both discrete-based and continuous-based variables. The level of awareness and the congestion of screening facilities are modeled as continuous variables because they change continuously over time. The number of screening facilities, the number of accessible primary care physicians (PCPs), the average number of servers per screening facility, the average distances to both screening facilities and PCPs, and the current screening level are modeled as discrete variables because they changed at discrete points in time. The remaining variables exhibited in Figure 3.1 are modeled as static input variables, for their values are not dynamic throughout the simulation, but are only capable of being changed by the user before running the simulation.

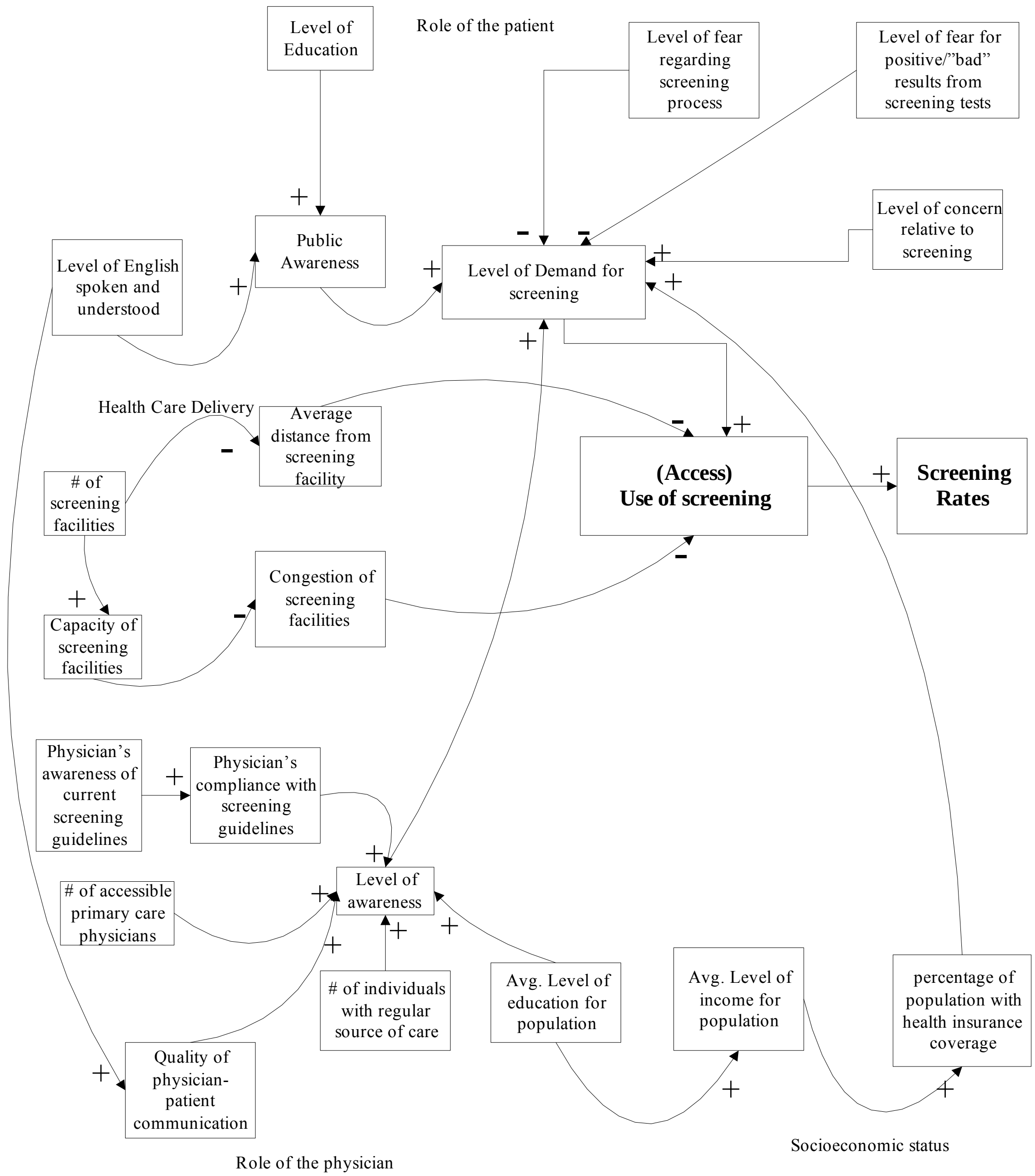

Figure 3.1: Causal Loop Diagram

3.3 The Arena Model

As mentioned above, the CCC system has discrete as well as continuous components. This feature of the system is modeled using combined discrete-continuous models in Arena, version 7.0. Arena is a commercial simulation language designed by Rockwell Software (W.David Kelton, Randall P.Sadowski, and Deborah A.Sadowski 2002).

Several variables are incorporated in addition to those mentioned above to help implement the simulation model in Arena. They are defined below in Table 3.1 along with a description.

Table 3.1: Variables with Description

Discrete Variables	Description
Number of Screening Facilities	The estimate for the number of screening facilities in NC
Avg Num of Servers per Facility	The average number of staff who perform colon cancer screening procedures in each facility in NC
Avg Distance from Facility	The average distance to a screening facility in NC
State Population	NC state population
State Rural Population	NC state rural population
Percentage of Pop 50 and Older	The percentage of the population in NC who are of age 50 and older
Percentage of State Rural Pop	The percentage of the population in NC who are in the rural areas of NC
Total PCP	The total number of primary care physicians in NC
Avg Rural Distance from Physician	The average distance from a primary care physician for someone who lives in a rural area in NC
Avg Distance from Physician	The general average distance from a primary care physician in NC
Screening Level	The total number of people (ages 50 and older) who have been screened for colon cancer (in NC)
Screening Rate	The percentage of people who have been screened out of the 50 and older population (in NC)
Congestion Product Value	A value used in the Congestion Rate equation, which is explained below in the *Methodologies* section

Discrete Variables continued	Description
G Procedures Daily	The average number of screening procedures performed by a gastroentertologist and a general surgeon on a daily basis
PCP Procedures Daily	The average number of screening procedures performed by a primary care physician on a daily basis
Present Demand	The current demand for colon cancer screening
Correctness of Info Exchange	The level representing how well the correct information exchanged between the physician and the patient
Physician Awareness of Screening Guidelines	The average level of the physicians' awareness of the colon cancer screening guidelines
Physician Compliance with Screening Guidelines	The average level of the physicians' compliance with the colon cancer screening guidelines
Level of Fear of Process	The patients' average level of fear of the whole screening process
Level of Fear of Results	The patients' average level of fear in getting bad results
Level of Concern	The patients' average level of concern with getting screened for colon cancer
Level of Standard English Spoken and Understood	The patients' average level of proficiency in English and use of the standard English language
Quality of Physician Patient Communication	Variable giving overall rating to the communication between the physician and the patient
Percentage No Show	The percentage of people who have demanded screening, but fail to show up to get screened
Patient Visits	The number of patient visits per day
Fifty and Older Visits	The percentage of patient visits with patients ages 50 and older
Level of Education	The average level of education for the NC population
Level of Income	The average level of income for the NC population
Percentage of Pop with Insurance	The average percentage of NC population under age 65 with health insurance
Social Support Network	The effect of a social support network on patient's adherence to screening recommendations
Confirmation of Communication	The effect of confirmation of communication on the quality of physician patient communication
Physician Reminder System	The effect of a physician reminder system on the physician's compliance with standard screening guidelines
Multimedia Intervention	The effect of multimedia intervention on the awareness level
Patient Reminder System	The effect of a patient reminder system on the percentage no show
Continuous Variables	
Awareness Level	An estimate for the number of people/patients who are aware of the colon cancer guidelines

Continuous Variables Continued	
Total Screening Demand Level	The number of patients who actually demand screening
Capacity Level	Represents the level of fullness of NC's resources for screening
Congestion Level	The average time interval between demand screening and actually getting screened

The discrete components of the system are modeled using the flowchart modules available on Arena's various modeling panels. The modules used in the discrete portion of the model include the *Create*, *Assign*, *Hold*, and *Dispose* modules. There are two *Create* modules used to form artificial entities in that the entities do not model real components of the system, but rather serve as a means for modeling the flow dynamics of the system. The creation of those entities represents the arrival of new PCPs and the development of new screening facilities. There are two *Assign* modules used to update several discrete variables, such as the number of PCPs, the number of screening facilities, the average distance to PCPs, and the average distance to a screening facility. A third *Assign* module is used to update the screening level and the capacity level (refer to Table 3.1). The *Hold* module is used to model the delayed response of the increase in the screening level to the demand for screening, which will be discussed later in detail. The *Dispose* module is simply incorporated to dispose of the entities created by the *Create* module.

The continuous components of the CCC system are modeled through Arena's continuous modules from the Elements Panel, and a Visual Basic for Applications programming interface (referred to as VBA). In particular, *Levels, Rates*, and *Continuous* modules are used. The *Levels* and *Rates* modules provide a means for defining what are known in Arena as *level* and *rate* variables, which are necessary to define continuous variables. In particular, these variables represent the variable's value and its rate of change over time, respectively. Therefore, there must be a one-to-one correspondence between *levels* and *rates*. In addition, these variables provide a means of communication between Arena and VBA (W.David Kelton, Randall P.Sadowski, and Deborah A.Sadowski 2002). In this study, there are four rate and level variables defined corresponding to the continuous variables mentioned above, and the rate of change is with respect to one day (days are used as the base time units).

The *Continuous* module is used to establish the settings that are needed to construct Arena's continuous calculations. For this study, continuous calculations are needed to solve simple, first-order differential equations used to specify rates of change in the levels. In this study, differential equations are defined because the continuous variables do not have constant rates of change; their rates change continuously over time. The number of differential equations is set in the *Continuous* module. Since each level/rate pair refers to a continuous variable with a variable rate of change, four differential equations are established. Furthermore, the preferred specifications and method for which these equations are solved are set in the *Continuous* module. For instance, there is a field to enter the minimum and maximum step sizes (.01 and .15 respectively), which dictate how often Arena updates and performs the continuous calculations. There is also a field in the *Continuous* module to select the integration algorithm to be used in the continuous calculations. The RKF (Runge-Kutta-Fehlberg) algorithm is selected for this study because as expressed earlier, the rates change continuously over time, and this method would yield more accurate value estimates (W.David Kelton, Randall P.Sadowski, and Deborah A.Sadowski 2002).

The differential equations are entered into the model via the VBA interface. Four differential equations are defined within this interface. They include equations to describe the rate of change in the awareness level, the total demand level, the capacity level, and the congestion level.

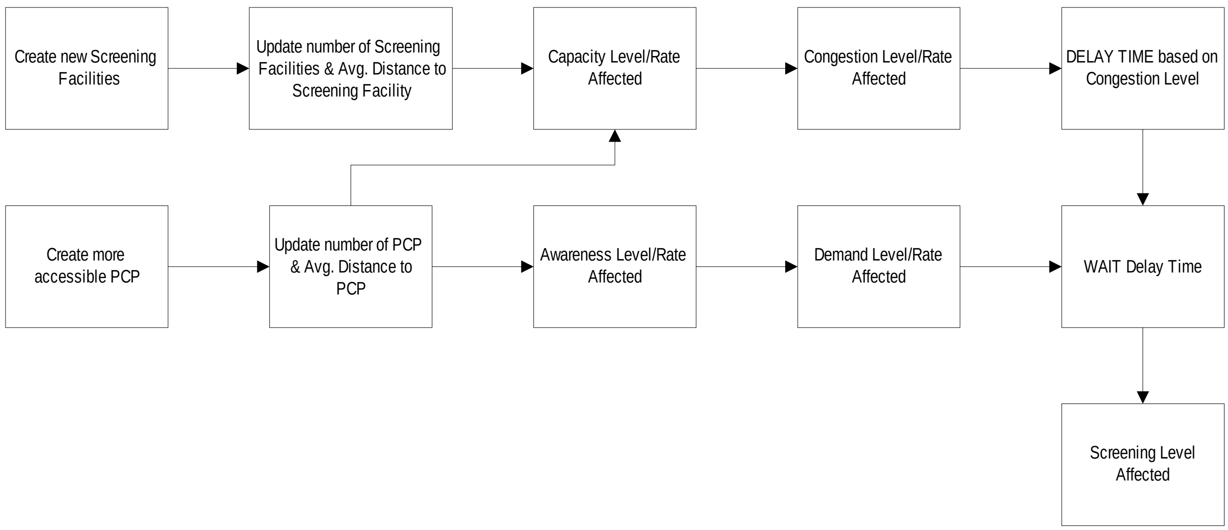

Figure 3.2: Logic Flow Diagram

3.4 Methodologies

Next, more specific information will be given regarding the methodology behind the mathematical modeling used within Arena for each sector of the CCC system. It is also important to note that all of the variables discussed in this section and latter sections regarding the role of the patient are averages representing the respective population, be it physicians or patients, as a whole. The reason for using averages, instead of random variables, is because this CCC system is being modeled on a large- scale basis.

3.4.1 Factor 1: Health Care Delivery

Many factors in this stage serve as the reasons for incorporating continuous models and VBA interface. The awareness level, screening demand level, capacity level, and congestion level all have continuous rates of change that change over time, and therefore need to be represented by differential equations.

3.4.1.1 The Awareness Level

As can be seen from Figure 3.1, the awareness level is a function of the number of accessible PCPs. It is important to note that accessible implicitly considers the distance factor. Therefore, the awareness level is actually a function of the distance to a PCP, which in turn is a function of the number of PCPs.

First, it is necessary to determine the average distance to a PCP in the rural North Carolina, and then estimate the average distance to a PCP based on mean of the rural distance, and the assumed distance of 12 miles for the urban area. The average rural distance to a PCP is formulated so that it can reflect the provider-to-patient ratio in the rural area. Based on statistics from the United States General Accounting Office (United States General Accounting Office 2003), the average PCP-to-patient ratio in metropolitan or urban North Carolina is approximately 1/1163, while the average PCP-to-patient ratio in nonmetropolitan or rural North Carolina is approximately 1/1852. The rural area has a smaller ratio because many of the rural North Carolina areas are designated as Health Professional Shortage Areas (North Carolina Rural Health Research Program 2004). In other words, these rural areas have a PCP-to-patient ratio that is smaller than the recommended ratio by the Department of Human Health and Services, which is 1 to 2000

(2003e). It is assumed that the average distance to reach a PCP in urban NC is approximately 12 miles and that this is relative to a PCP-to-patient ratio of 1/1200; this assumption allows leeway for depletion of PCPs in urban NC and thus maintenance of the access level (with regards to distance).

Furthermore, a good estimate for the rural mileage is between 60 and 120 miles (CAH/FLEX National Tracking Project Consortium Members 2001). Therefore, it is necessary to have an equation that would yield between 60 and 120 miles for the rural area ratio, and 12 miles based on the 1 to 1200 ratio. The following equation was constructed to capture those properties, as well as remain consistent in producing reasonable mileage values for other ratios. For instance, the urban PCP-to-patient ratio is 1/1200 and therefore, 1/Ratio = 1200, yielding an average urban distance of 12.4 miles (or ~ 12 miles). Also, the initial rural PCP-to-patient ratio is 1/1852 and therefore, 1/Ratio = 1852, yielding an average rural distance of 80.2 miles.

$$\mathit{Avg\ Rural\ Distance\ from\ Physician} = \left(\left(\frac{1}{\text{Ratio}}\right) + \left(\left(\frac{1}{\text{Ratio}}\right) - 1200\right)\right) * .052 - 50$$

Equation 3.1

where the *Ratio(PCP-to-patient ratio)* is = $\dfrac{\#\,PCPs\ in\ rual\ area}{rural\ population}$

Equation 3.2

It is important to note that the right-hand side of Equation 3.1 is referred to as the variable *Avg Rural Distance from Physician* simply because the urban distance remains constant. Also, this equation is only applicable where the value of $\frac{1}{Ratio}$ is ≥ 1200, or what is referred to as the "target value". Furthermore, this equation reflects how the magnitude of the difference from the target contributes to the distance as well.

In turn, when the simulation model creates additional PCPs, they are just added to the rural PCPs in an effort to decrease the ratio, and consequently decrease the rural distance. As a result, the general average distance to a PCP will decrease. The average distance to a PCP is formulated as a weighted average, where the weights are the rural population percentage and urban population percentage (Elizabeth Beeson and Marty Strange 2003). The expression is the following:

$$Avg\ Distance\ from\ Physician =$$

$$rural\ \ population\ \% * avg\ rural\ distance + urban\ \ population\ \% * avg\ urban\ distance$$

Equation 3.3

It is the value of the *Avg Distance from Physician* that is actually reflected in the equation for the Awareness rate.

The awareness rate is interpreted as the number of people who become aware or are informed of CRC screening. Initially, this number is dependent on the number of patients seen per day by a PCP. The number of patient visits per day varies over the simulation run. The awareness rate includes the number of first visits made by established patients, and new patient visits (Donald K.Cherry and Catharine W.Burt 2003) for the first year. The reason for only including first visits is to avoid overestimating the awareness rate. Moreover, for the following years, the awareness rate just includes new patient visits. This adjustment is due to the assumption that once a visit is made, it is then that the patient has the opportunity to be informed of CRC screening. Therefore, new incoming patients would only affect the increase in awareness. It is apparent that the equation must incorporate the average number of patients seen per day as well as the distance factor. The initial expression for the awareness rate is the following:

Awareness Rate =

$$((Patient\ Visits * Old\ \ physicians) + (16 * New\ physicians))* \frac{12}{Avg\ dist\ \ from\ \ physician * 0.1 * Avg\ dist\ \ from\ physician}$$

Equation 3.4

Note that for simplification purposes, *Avg dist from physician* in Equation 3.4 represents the variable *Avg Distance from Physician*. As can be seen in Equation 3.4, two new variables have been introduced, Old physicians and New physicians (their total equating to *Total PCP*). A PCP is considered to have new physician status upon their arrival to the CCC system and during the remainder of their first year. During that first year a new physician's average number of daily patient visits is equal to 16, which is based on data regarding average number of patient visits per week (2004f), and the assumptions that there are 7 days per work week, and all of the patients during this first year are new patients. After the first year that PCP then acquires the old physician status and the number of patients seen becomes based upon the associated variable *Patient Visits*.

Furthermore, Equation 3.4 is also appropriate because it provides an upper bound for the awareness rate. The value of *((Patient Visits * Old physicians)+(16 * New physicians))* is an upper bound for this expression's value, since the lowest possible value for the variable *Avg dist from physician* is 12 miles. Also, it is important to note that Equation 3.4 is the initial expression for the awareness rate because other factors that affect the awareness rate are considered later. The updated equation for the awareness rate is mentioned later within the section for the Role of the Physician (Section 3.4.2).

3.4.1.2 The Demand Level

The Demand Level is interpreted as the number of persons demanding colon cancer screening. The demand rate for the first year and the demand rate for the following years are modeled differently due to the nature of the awareness rate for the respective year.

The demand rate for the first year is modeled as the awareness rate multiplied by the percentage of the patient visits where patients are of age 50 and older (American Cancer Society recommends regular screening for colon cancer for those persons at age 50 and older (American Cancer Society 1999), minus the percentage of those patients who have been screened. The logic behind this approach is based on two main assumptions. As mentioned earlier, established patients contribute to the awareness level during the first year. The second assumption is that those who have been screened are included in the established patients. Therefore, to get better estimates for the increase in the screening level, when calculating the demand, the patients that have already been screening must be excluded in the awareness rate. This computation removes the percentage of the established patients who have been screened from the demand rate.

The demand rate for the following years is modeled as the awareness rate multiplied by the percentage of the patient visits that represent patients of ages 50 and older. This approach was chosen because the awareness rate in all of the years following the first year includes only new patient visits. Therefore, in this case it is unnecessary to account for those patients who have already been screened.

Statistics from the Centers for Disease Control's (CDC) National Ambulatory Medical Care Survey (NAMCS) and the US Census Bureau are used to estimate the percentage of patient visits where the patient is age 50 or older. The CDC Advance Data Report shows that 53.1 percent of visits are by patients ages 45 and over (Donald K.Cherry and Catharine W.Burt 2003). Furthermore, statistics from the US Census Bureau show that the group including ages 45 to 49 constitute 7 percent of the NC population (2004d). Therefore, an estimate for the percentage of those patient visits comprised of persons ages 50 and older is the following:

$$\textit{50 and Older Visits} = 53.1\% - (7\%*53.1\%) \approx 49.4\%$$

The initial expression for the first year demand rate is the following:

Total Screening Demand Rate = (50 *and Older Visits***Awareness Rate)* - 0.3045**Awareness Rate for Established patients*

Equation 3.5

The value 0.3045 corresponds to the percentage of the 50 and older population that has already been screened (American Cancer Society 2002).

The initial expression for the demand rate after the first year is the following:

Total Screening Demand Rate = (50 *and Older Visits*)**Awareness Rate*

Equation 3.6

It is important to note that Equation 3.5 and Equation 3.6 are the initial expressions for the demand rate for the first year and following years, respectively. Both are needed because as other factors are considered later, the demand rate changes. The final updated equations for the demand rate are mentioned later within Section 3.4.4 for the Socioeconomic Factors.

3.4.1.3 The Capacity Level

The capacity level is interpreted and modeled as the ratio of the demand to the capacity available amongst the screening facilities. Therefore, in modeling the capacity rate, which is the ratio per day, the need exists to incorporate the number of screening facilities, the number of screening practitioners within the screening facilities, and the number of patients seen per day by the screening practitioners.

According to the National Cancer Institute (NCI) Survey of Colorectal Cancer Screening Practices, the pool of physicians who perform colorectal cancer screening procedures is comprised of PCPs, gastroenterologists, and general surgeons (Martin L.Brown, Carrie N.Klabunde, and Pauline Mysliwiec 2003). Therefore, in modeling the capacity rate, which is the ratio per day, the number of screening facilities, the number of screening practitioners within the screening facilities, and the number of patients seen per day by the screening practitioners. The expression for the capacity rate is as follows:

Capacity Rate =

$$\frac{PresentDemand}{(NumFacilties * NumServers * GProcedres) + (0.3 * NumPhysicians * PCPProcedures)}$$

Equation 3.7

Present Demand signifies the new demand for the day (present demand rate). *NumFacilities*, *NumServers*, and *GProcedures* represent the variables *Number of Screening Facilities*, *Avg Num of Servers per Facility*, and *G Procedures Daily*, respectively (described above in Table 3.1). Similarly, *NumPhysicians* and *PCPProcedures* represent the variables *Total PCP* and *PCP Procedures Daily*, respectively (described above in Table 3.1). In addition, the value of 0.3 is used because according to the National Cancer Institute Survey (Martin L.Brown, Carrie N.Klabunde, and Pauline Mysliwiec 2003), only 30% of PCPs actually perform colorectal screening procedures.

3.4.1.4 The Congestion Level

The congestion level is modeled as a time interval. Essentially, it is interpreted as the time from when the patient demands screening until the time he/she actually gets screened. Thus, the factors that contribute to this are the average distance to a facility and the capacity of the screening facilities.

The average distance from a screening facility is modeled as a function of the number of screening facilities. The model needs to capture a function that is exponential in nature. The reason for this is that the rate of decrease in distance decreases as the number of screening facilities increases.

A type of logistic function is incorporated into the expression for the average distance to capture that property. The logistic function was chosen to be a component of the expression because it represents a function that grows exponentially, but also that is bounded by horizontal asymptotes. Logistic functions in general are good for modeling resource limited growth. In this case, the number of screening facilities is limited in growth. The expression for the average distance to the facility is the following:

Avg Distance from Facility =

$$\frac{2000}{(1+0.8^{-Number\ of\ Screening\ Facilities})}+\frac{(100 - Number\ of\ Screening\ Facilities)}{(0.1 * Number\ of\ Screening\ Facilities)}$$

Equation 3.8

The left component of the formula models the general logistic function, f(x) = $\frac{a}{(1+bc^{-x})}$ (2004b). Here, if c^{-x} grows with 0<c<1, then the denominator will grow as well, thus driving the function entirely to 0. This behavior is what needs to be captured because as the screening facilities increase, the distance should logically get shorter. Furthermore, the right component of Equation 3.8 is used for scaling purposes in an effort to render close to realistic values for the average distance with respect to the number of screening facilities. Also, the American Cancer Society (ACS) NC Hospital/Healthcare facility Profile web site, where it mentions that current screening facilities are within an average distance of 40 miles, is used as a reference in determining the expression in Equation 3.8 (2004a).

The expression for the Congestion Rate is the following:

$$\text{Congestion Rate} = (\text{Capacity Rate} * \text{Dist to Facility} - \text{Congestion Product Value})*200$$

Equation 3.9

Dist to Facility represents the variable *Avg Distance from Facility* (refer to Table 3.1). *Congestion Product Value* represents the old value of the product *Capacity Rate* * *Dist to Facility*. The reason for this relationship is that if that product of terms stays unchanged, then the congestion level will remain the same since the congestion rate will consequently be equal to zero. In addition, by subtracting that product value, the change in the congestion level will be consistent with the change in the interaction between the average distance and the capacity rate. Hence, when the product value increases, the congestion level increases, and when the product value decreases, the congestion level decreases accordingly. Finally, the value of 200 is used to scale the congestion rate and to get realistic values for the time delay.

3.4.2 Factor 2: Role of the Physician

The physician has a substantial role in the CCC system, and his/her relationship with the patient affects the patient's compliance with the colon cancer screening guidelines. Three variables have been formulated that comprise this factor. They include *Quality of Physician Patient Communication*, *Physician Awareness of Screening Guidelines*, and *Physician Compliance with Screening Guidelines*.

As illustrated above in Figure 3.1, *Quality of Physician Patient Communication* directly affects the awareness rate. This variable is modeled on a 0 to 1 scale, 0 representing the lowest level and 1 representing the highest level, because it represents a "quality," and this is a reasonable means for rating this quality. To account for the effect of this quality on the awareness rate, the awareness rate is reduced by the *Quality of Physician Patient Communication*. The updated expression for the awareness rate is as follows:

$$\text{Awareness } Rate = Awareness\ Rate_{(Equation\ 3.4)} * Quality$$

Equation 3.10

For simplification purposes, *Quality* represents the variable *Quality of Physician Patient Communication*. Furthermore, the *Quality of Physician Patient Communication* is allowed to encompass just the correct transfer of information; the variables that reflect this are described below in the Role of the Patient Section (Section 3.4.3).

As illustrated above, the *Physician Awareness of Screening Guidelines*, and *Physician Compliance with Screening Guidelines* affect the awareness rate. The assumption is made that if PCPs are unaware of the screening guidelines, then the vital importance of screening would not be relayed to the patients. Moreover, if PCPs are not in compliance with the screening guidelines, then their patients would be unlikely to receive recommendations to get screened.

Both variables are modeled on a 0 to 1 scale, 0 representing the lowest level and 1 representing the highest level, because they represent a "quality" as well. More specifically, the weighted average of the 0 to 1 values for the *Physician Awareness of Screening Guidelines*, and *Physician Compliance with Screening Guidelines* is modeled as a fraction of patients who visit their PCP, and actually become informed of the screening guidelines. The next expression is the weighted average of these two variables:

Weighted average of Factor 2 variables =

Physician Awareness of Screening Guidelines * 0.3 + *Physician Compliance with Screening Guidelines* * 0.7

Equation 3.11

This yields the final updated equation for the Awareness Rate:

$Awareness\ Rate = Awareness\ Rate_{(Equation\ 3.10)} * Weighted\ average\ of\ Factor\ 2\ variables_{(Equation\ 3.11)}$

Equation 3.12

This weighted average, giving more weight to compliance, reflects the affect of *physician compliance* on *physician awareness*, and how ultimately it is the compliance that governs the chances of the standard CRC screening guidelines being communicated to the patient. For instance, if the physician has a high awareness, but low compliance, the chances of the patient receiving standard recommendations for screening greatly decreases, which in turn is reflected in the resulting average. Also, if the physician has a high awareness, and high compliance, then the patient has a good chance of being offered standard recommendations for screening, while if the physician has a low awareness as well as low compliance, then the patient has a very low chance of being offered standard recommendations for screening.

3.4.3 Factor 3: Role of the Patient

The main factors that constitute the role of the patient are relevant to the patient's ability to communicate with the physician, and his/her emotions about the screening process. Specifically, four different variables are used and referred to as the *Level of Standard English Spoken and Understood*, the *Level of Fear of Process*, the *Level of Fear of Results*, and the *Level of Concern* (refer to Table 3.1). All of these variables are modeled on a 0 to 1 scale, 0 being the lowest level and 1 being the highest level, because again they represent a certain type of "quality".

The *Level of Standard English Spoken and Understood* not only encompasses the proficiency in the general English language, which many times becomes an issue with reference to foreign communities, but also the level of use of the standard English language. Patients from different cultural backgrounds may not necessarily use the standard language spoken by the health professional, which of course can serve as a barrier in the transfer of information. (Dona R.Falvo 1994). The *Level of Standard English Spoken and Understood* is modeled as a component of the *Quality of Physician Patient Communication*. The expression for the *Quality of Physician Patient Communication* is the following:

$$\textit{Quality of Physician Patient Communication} =$$

$$\textit{Correctness of Info Exchange} * 0.6 + \textit{Level of Standard English Spoken and Understood} * 0.4$$

Equation 3.13

The *Correctness of Info Exchange* simply refers to how successfully the correct information is exchanged. The *Quality of Physician Patient Communication* is a weighted average of the two factors because they do not equally affect the quality of communication. The *Correctness of Info Exchange* is slightly more influential than the *Level of Standard English Spoken and Understood*; for, if the information is not exchanged correctly, the wrong information is now in hands of the patient, regardless if he/she uses standard English or even speaks English at all. Furthermore, the numbers 0.6 and 0.4 are used to reflect that the *Correctness of Info Exchange* is only slightly more influential, and the *Level of Standard English Spoken and Understood* is still fairly important.

The *Level of Fear of Process*, *Level of Fear of Results*, and *Level of Concern* are all 0 to 1 variables reflecting emotions of the patient that directly affect the demand rate. For simplicity, let *ProcessFear, ResultFear*, and *Concern* represent *Level of Fear of Process*, *Level of Fear of Results*, and *Level of Concern*, respectively. Then, the next updated expression for the demand rate is as follows:

$$\textit{Total Screening Demand Rate} = \textit{Total Screening Demand Rate}_{(\textit{Equation 3.5 or Equation 3.6})} * (1 - (\textit{ProcessFear} * 0.20 + \textit{ResultFear} * 0.20 + (1 - \textit{Concern}) * 0.6))$$

Equation 3.14

As can be seen from Equation 3.14, the emotions of the patient influence whether or not they will demand screening. Equation 3.14 further illustrates that these emotional components determine what percentage of the patients who have correctly received the CRC screening information actually demand to get screened. This percentage is equal to the weighted average of the emotional component variable values subtracted from 1.

Also, here the *Total Screening Demand Rate*$_{(Equation\ 3.5\ or\ Equation\ 3.6)}$ incorporates the updated awareness rate from Equation 3.12.

The *Level of Fear of Process* and the *Level of Fear of Results* are considered to be adverse qualities. On the contrary, the *Level of Concern* is a positive quality, which is why its value is subtracted from 1 to use its complement as an "adverse" quality with the other two variables. This weighted average of the emotional component variables is used because it is important to capture how the *Level of Concern* ultimately dictates the patient's value for their health and their willingness to comply with his/her PCP's recommendations. Also, in reality when the level of concern is high, it definitely can override the level of fear.

3.4.4 Factor 4: Socioeconomic Factors

Several variables are associated with the socioeconomic factor in the existence of problems with accessing CRC care. The variables include *Level of Education*, *Level of Income*, and *Percentage of Pop with Insurance*. The description of these variables can be found above in Table 3.1.

The variables *Level of Education* and *Level of Income* are modeled as 0 to 1 variables because they represent a "quality". These are generated from scales for both *the Level of Education*, and the *Level of Income*. The scale for the *Level of Education* is as follows:

Let x: *Level of Education*

$0.0 \leq x < 0.28$: less than 9th grade education
$0.28 \leq x < 0.42$: less than High School education
$0.42 \leq x < 0.56$: High School graduate
$0.56 \leq x < 0.70$: Some College

$0.70 \le x < 0.84$: Associates Degree
$0.84 \le x < 0.98$: College Graduate
$0.98 \le x < 1.0$: Graduate level or Professional level education

The scale for the *Level of Income* is as follows:

0.2: poverty
0.4: low income
0.6: medium income
0.8: high income
1.0: very high income.

A program in VBA constructs a mapping between the *Level of Education* and *Level of Income* based on data that give average income values as a function of the education level (Amarillo College et al. 2004;Bureau of the Census 1998). The standard US Census Bureau poverty threshold definitions and guidelines were used to determine income status based on income level and the assumption that income includes only the individual's income, rather than household income (2002;2004e). Once the income status is determined, the VBA program then maps the level of income to a particular value representing the percentage of the population under age 65 with health insurance, which is based upon data from Henry J. Kaiser Family NC State Health Facts online (2004c). Only those individuals under the age of 65 are included because Medicare covers those persons of 65 years of age and older (Gregory L.Weiss and Lynee E.Lonnquist 2000).

Furthermore, the percentage of population with health insurance affects the demand rate for screening. The percentage of persons uninsured who skip a recommended screening is computed from:

X = *Nonmedicare visits**(1- *percentage of pop with insurance*)*0.34,

Equation 3.15

where *Nonmedicare visits* includes the percentage of patients without Medicare and 0.34, a figure based on a survey (Lisa Duchon et al. 2001), represents the percentage of uninsured patients that skip a screening exam. Now, the final expression for the demand rate is as follows, where the result from Equation 3.15 is represented by X:

$$\textit{Total Screening Demand Rate} = \textit{Total Screening Demand Rate}_{(\textit{Equation 3.14})} * (1-X)$$

Equation 3.16

3.5 Input Data Calculations, Estimations, and Additional Assumptions

A major component of the simulation model is the input data. The majority of the data have been directly retrieved from reliable sources, which are listed in the References, while some data have been constructed indirectly from other data and assumptions that have been made. This section will review how the data in the latter case have been derived, and the relevant assumptions made along the way.

Before moving further, it is important to note that most of the input data reflect the conditions of the CCC system in the year 2000. This year was chosen because the most accurate readily available demographic data are for the year 2000. In turn, in an effort to maintain consistency, the other initial data needed for the simulation is based on statistics from the year 2000.

Furthermore, it is assumed that the awareness level and demand level are equal to zero at the beginning of the simulation. By initializing the awareness and demand levels to zero, the model can represent these levels beginning in the first year of the simulation and ending in the final year. In other words, this approach provides a fresh look to the behaviors of the awareness level and demand level. In turn, initializing these levels to zero will also capture those persons who have become aware or informed, and who have demanded screening over the length of the simulation run.

The screening level, however, is initialized to the current screening level. This scheme is used because the simulation needs to reflect the changes in the screening level. The simulation computes the initial current screening level based on an average screening rate (~30.45%) retrieved from ACS data (American Cancer Society 2002), and the fifty and older NC population (2004d). The initial value for the screening level was calculated to be 674029.

Furthermore, the capacity level is initialized to zero, while the congestion level is initialized to 35 days. The reason for this is because having zero demand in the system initially indirectly yields a value of zero for the capacity level. The congestion level is set to 35 days because this is a reasonable time for a person to get screened irrespective of the CCC system's characteristics; therefore, the simulation can reflect how the congestion level is affected, whether positively or negatively, by the conditions of the CCC system.

The initial values for the following variables are not readily available, and therefore, have to be estimated. The techniques used to estimate the variable values are described below.

Total PCP

According to the CDC Health and Vital Statistics (Donald K.Cherry and Catharine W.Burt 2003), the majority of PCP are in the practices of general and family practice, internal medicine, obstetrics and gynecology, cardiovascular disease, general surgery, and pediatrics. However, because we are concerned only with adults, the PCPs in the field of pediatrics are excluded from this study. Based on the Henry J. Kaiser Family Foundation State Health Facts Online (2003d), there were 6602 PCPs in NC, excluding pediatricians, who constitute on average 18% of NC PCPs, in the year 2002. Furthermore, based on North Carolina Health Professions data (2003c), there is an average increase in PCPs of 429 from 2000 to 2002. Therefore, an estimated number of PCPs in 2000, excluding pediatricians, is 6250.

Patient visits

The average capacity for the number of patient visits per day per PCP is based on data regarding average number of patient visits per week (2004f), and the assumption that there are seven days per work week for PCPs. In general, seven days per week is based on the assumption that in the real world there are 7 days per week and 365 days per year, and the fact that numerical figures partly derived from this base time period were able to be approximated the most accurately from the data used for this research. In addition, it is important to note that although this assumption might introduce bias numerically, it does not misrepresent behavior of the model, which is the central focus of this study.

The number of first visits by established patients is not readily available. The authors of the CDC Advance Data Vital and Health Statistics (Donald K.Cherry and Catharine W.Burt 2003) document report this type of visit but, report it in terms of categories. Data are given for established patient visits in which there were one to two visits, three to five visits, and six or more visits. To get just the number of first visits, the average numbers of first visits for each of the categories are computed, and then the respective numbers are totaled to get the percentage of the first visits made by established patients. Finally, that percentage is multiplied by the PCP patient visit capacity.

For example, suppose the data for established patient visits consisted of 10 of type 1-2 visits, 12 of type 3-5 visits, and 36 of type 6 or more visits. Then an assumption is made that for the type 1-2 visits, the average is 2 visits; for the type 3-5 visits, the average is 4 visits; and for the type 6 or more visits, the average is 6 visits. Therefore, these assumptions yield an average of 5 first time visits of type 1-2 visits, 3 first time visits of type 3-5 visits, and 6 first time visits of type 6 or more visits. In turn a total of 14 first time visits for established patients is obtained and a value of 24.14% is calculated, which represents the portion of established patient visits that are first time visits. Therefore, 24.14% is used as the basis for determining the number of first time established patient visits for a PCP.

Screening capacity

The number of screening procedures performed daily is needed to estimate screening capacity. The NCI survey (Martin L.Brown, Carrie N.Klabunde, and Pauline Mysliwiec 2003) reports monthly averages for the performances of these procedures. Again, by assuming that there are seven days per work week and an average of 4 weeks per month, the monthly averages are divided by 28 to get estimates for the daily screening procedure capacities.

Furthermore, an estimate of 23 screening facilities was retrieved by running a query on the American Cancer Society (ACS) NC Hospital/Healthcare facility Profile web site to locate healthcare centers that provide CRC screening (2004a). Also, an estimate of 25 screening practitioners has been configured from data gathered on the same web site.

Percentage no show

The *Percentage No Show* adversely affects the screening level. This variable captures the percentage of people who do not comply with the screening recommendations due to the fact that they simply miss the appointment, or forget the appointment all together for miscellaneous reasons. An initial value of 0.30 is assigned to *Percentage No Show*. This figure is based on the fact that two sources (Martin L.Brown, Carrie N.Klabunde, and Pauline Mysliwiec 2003;Reid M.Ness 2001) report similar values to represent the same kind of occurrence.

Level of Education

As mentioned earlier in Section 3.4.4 there is a scale for the level of education. The variable *Level of Education* (definition described above in Table 3.1) is initialized as a weighted average of the different level values for the NC population (2000) where the weights are the percentage of the population with each respective level of education. After calculations, the *Level of Education* is assigned a value of 0.53.

Changes in the population

It is assumed that during the simulation run, the NC population does increase. Based on historical NC population data for the past three years provided by the US Census Bureau (2003a;2004d), the average percent increase in the NC population is 0.0146.

However another assumption is that the fifty and older population of NC remains the same. This assumption is based on data from the US Census Bureau (2004d). The assumption is also made that the rural population percentage will remain constant over the simulation period.

In summary, the simulation model is very complex as it models an intricate system. The simulation model has been designed to reflect each factor that serves as a barrier of the CCC system, as well as the interactions among the factors so that the true behavior of the system may be well represented when performing simulation experiments. The following chapters explain why the simulation model is appropriate and how it will well reflect the effects of variable changes and intervention schemes, discussed below, on the CCC system as a whole.

3.6 Verification

Verification is concerned with making sure the model executes as expected. The approach taken to verifying the Arena model consists of several aspects. In an effort to facilitate the verification process, the simulation model was constructed in progressive stages. The first stage incorporates the health care delivery factor (basic model); the second stage includes the health care delivery factor in conjunction with the role of the physician; the third stage includes the health care delivery factor in conjunction with the role of the physician and the role of the patient; and finally the fourth stage encompasses the health care delivery factor, the roles of the physician and the patient, and the socioeconomic factor.

As a result of the structure of the model, each stage was tested individually during the verification process. The purpose in testing each progressive stage individually is to ensure that the model performs as intended in transitioning from one stage to another, and consequently to ensure that there are appropriate interactions among the several factors.

Several verification tests were performed that were generally applicable to every stage throughout the model. First, the calculations were checked to make sure they were being performed correctly in VBA. This task employed the Arena debugger and also required stepping through the VBA code while in run mode. The capacity level was also checked to be sure it was being affected correctly when demand exited the system. This task was accomplished by stepping through the Arena model via the run controller, which provided access to the current values of the variables at different points in time (simulation time) throughout the simulation run.

Furthermore, the verification process included varying different variable values and confirming their proper effects on the awareness level, demand level, and screening level. The conditions that were tested varied from stage to stage. For instance, for the first stage, extreme conditions for screening facility and PCP capacity were tested, whereas for the second stage, extreme conditions for the physician level of awareness, physician level of compliance, and the quality of physician patient communication were examined. For the third stage, the values for the patient's levels of fear, level of concern, level of standard English, and level of correctness of the exchange of information were varied. Finally, for the fourth stage the level of education was altered. Table 4.1 illustrates that the behavior of the model under the various testing conditions was sensible, and captured reasonable effects.

For example, in reference to stage 1, as the PCP accessibility improves in the rural area, there is an increase in the awareness level, demand level, and as a result, the screening level. However, when there is just an increase in the number of screening facilities, the increase in the screening level is not as significant. Furthermore, having both an increase in the number of PCPs in the rural area and in the number of screening facilities, according to the conditions set in scenarios 3 and 5, allows for a greater significant increase in the screening level.

In reference to stage 2, the verification results show, for example, that the screening level will be considerably lower when the physician awareness, physician compliance, and quality of physician patient communication levels are at very low values than when they are at very high values (676763 vs. 948754).

Similarly, in reference to stage 3, the verification results illustrate, for example, that there is a significant difference in the screening level when the Role of the Patient factor variables are at their optimum levels (scenario 10) versus when they are at unsatisfactory levels (scenario 12), 948754 versus 697745, respectively.

Finally, in reference to stage 4, the verification results illustrate that incorporating the education level does impact the performance of the CCC system. For example, even when the education level is at its optimum value, the screening level is still lower than that for when the Role of the Physician and Role of the Patient factor variables were at their optimum values (946165 vs. 948754). This makes sense because the education level indirectly incorporates the percentage of the population with health insurance, which ultimately affects the number of persons who get screened. Furthermore, the verification results illustrate sensibility in that the screening level is higher when the education level is at its highest level than when it is at a very low level (946415 vs. 940884).

Table 3.2: Verification Results

**Note: For those entries with Expo(α, *i*), α = mean, and UNIF(a, b, *j*), *i* and *j* are random number streams
**Run length: 1095 days
** Values other than screening rate rounded up to the nearest integer

HEALTH CARE DELIVERY (Stage 1)			
Scenario 1:	BASE CASE with zero increase in resource capacity		
Awareness Level	Demand Level	Screening Rate	Screening Level
1221697	395638	0.4164	948754
Scenario 2:	PCP Interarrival Time: Expo(60,3) days Entities per Arrival: UNIF(5,20,5) Max Arrivals: 15 (Arrivals to Rural Area)		
Awareness Level	Demand Level	Screening Rate	Screening Level
1367866	447018	0.431	982125
Scenario 3:	PCP Interarrival Time: Expo(30,3) days Entities per Arrival: UNIF(20,35,5) Max Arrivals: 15 (Arrivals to Rural Area)		
Awareness Level	Demand Level	Screening Rate	Screening Level
2100446	724142	0.4994	1137992
Scenario 4:	Screening Facility Interarrival Time: Expo(365,2) days Entities per Arrival:UNIF(2,5,4) Max Arrivals: 3		
Awareness Level	Demand Level	Screening Rate	Screening Level
1221697	395638	0.4164	948874
Scenario 5:	Screening Facility Interarrival Time: Expo(180,2) days Entities per Arrival:UNIF(5,10,4) Max Arrivals: 10		
Awareness Level	Demand Level	Screening Rate	Screening Level
1221697	395638	0.4168	949719
Scenario 6:	Scenario 3 and Scenario 5 combined		
Awareness Level	Demand Level	Screening Rate	Screening Level
2100446	724142	0.5128	1168582
ROLE OF THE PHYSICIAN (stage 2) with zero increase in resource capacity			
Scenario 7:	Physician Awareness = 1, Physician Compliance = 1, Quality = 1		
Awareness Level	Demand Level	Screening Rate	Screening Level
1221697	395638	0.4164	948754
Scenario 8:	Physician Awareness = .1, Physician Compliance = .1, Quality = .1		
Awareness Level	Demand Level	Screening Rate	Screening Level
12217	3957	0.297	676763
Scenario 9:	Physician Awareness = 1, Physician Compliance = 1, Quality = .1		
Awareness Level	Demand Level	Screening Rate	Screening Level
122170	39564	0.3078	701417

ROLE OF THE PATIENT (stage 3) with zero increase in resource capacity			
Scenario 10:	Level of fear of process = 0, Level of fear of results = 0, level of concern = 1 Level of standard English = 1, correctness in info. Exchange = 1		
Awareness Level	Demand Level	Screening Rate	Screening Level
1221697	395638	0.4164	948754
Scenario 11:	Level of fear of process = 0, Level of fear of results = 0, level of concern = 1 Level of standard English = 1, correctness in info. Exchange = .1		
Awareness Level	Demand Level	Screening Rate	Screening Level
561981	181994	0.3511	800069
Scenario 12:	Level of fear of process = .7, Level of fear of results = .7, level of concern = .4 Level of standard English = .3, correctness in info. Exchange = .2		
Awareness Level	Demand Level	Screening Rate	Screening Level
293208	34183	0.3062	697745
SOCIOECONOMIC FACTORS (stage 4) with zero increase in resource capacity			
Scenario 13:	Level of Education = 1		
Awareness Level	Demand Level	Screening Rate	Screening Level
1221697	392665	0.4153	946415
Scenario 14:	Level of Education = .1		
Awareness Level	Demand Level	Screening Rate	Screening Level
1221697	384340	0.4129	940884

3.7 Validation

Validation involves ensuring that the model behaves the same as the "real world system". Achieving the goal of full validation for this particular CCC system is never-ending. It is not possible to observe all the activities and interactions within the model. In other words, the CCC system is not a tangible system as is a waiting area at a doctor's office or an assembly line for a manufacturing company. Therefore, it is not possible to obtain all of the massive data reflecting the behavior of the CCC system in the "real world", which is necessary to prove the simulation model behaves similarly to the "real world system". Consequently, only portions of the model can be validated. It is possible using the input data that drives the simulation to illustrate the credibility of the simulation model by predicting circumstances for which other data exist. This approach provides a means of validating the behavior of the simulation model.

The sources of input data used give very reliable statistics, some of which include statistics for the demographics of North Carolina, screening rates for CRC, intricate characteristics of patient visits to physician offices, and disparities within health care in general. Some of the data sources include the U.S. Census Bureau, the American Cancer Society, the Henry J. Kaiser Family Foundation State Health Facts (for NC), the National Center for Health Statistics, the North Carolina Professions Data System, and the North Carolina Rural Health Research and Policy Analysis Cartographic Archive.

Moreover, credibility is used as a means for illustrating validity for the simulation model. Specifically the model is used to demonstrate that it captures many known behaviors. The results below demonstrate that the simulation model does produce these same known behaviors and interactions among different factors.

An example of a known behavior can be observed by increasing PCPs in the urban areas of NC. In this case the screening rate should not improve significantly as with an increase in rural PCPs. For instance, in Table 3.3A it is apparent that as the run length increases (thereby allowing for more PCPs), the rate of increase in the screening level when PCPs arrive to the rural areas is much lower than that for when PCPs arrive to the urban areas, 56810 versus 76529, respectively.

A second example of a known behavior is that an increase in the demand level does not guarantee an increase in the screening rate accordingly because the effect of increase in resource demand is limited by less resource availability. For instance, Table

3.4 illustrates in scenarios A and C that when demand increases from 392928 to 599566, yielding a difference of 206638, the screening level does not reflect the same change in that it only increases by 163203. Scenarios C and E reflect a more powerful perception of this occurrence; the increase in the demand level far surpasses the increase in the screening level, 352664 versus 181930, respectively. Hence, these results clearly show that by not increasing the screening facilities, all of the demand cannot be met.

Furthermore, results of Table 3.4 show that the screening level in general is lower (comparing results of Table 3.4 with Table 3.3B) when just the PCP capacity is increased compared to when the both PCP capacity and the number of screening facilities are increased.

A third example is that an increase in physician awareness can be futile if the compliance is relatively low. For example, Table 3.5 shows that when the PCP Awareness increases from 0.4 to 1, the screening rate increases minimally (by 1.5%). This occurs because the compliance remains at a low value of 0.25. It is only when the compliance increases reasonably that a significant improvement is exhibited in the screening rate. Table 3.5 also shows that when the compliance is increased to 0.8, the screening rate increases by an additional 3.1%.

Another example is that even if a patient has fear of getting screened, his/her concern for his/her health has more weight in deciding whether or not to get screened. For instance, Table 3.6 illustrates that when the fear levels decrease by 0.7 to a value of 0.2, the screening rate does improve slightly, verifying that fear does have an impact. However, the screening rate does not significantly increase until there is also a higher level of concern. The screening rate increases by an additional 3.4 % when the level of concern is increased by 0.7 to a value of 0.95. In addition, the last scenario of Table 3.6 illustrates how the level of concern has more weight than the level of fear. Notice that when the fear levels remain at the initial values of 0.9, but the level of concern increases by 0.75, the improvement in the screening rate is better than that for the first scenario involving decreasing the fear levels by 0.7 and leaving the level of concern at a low value of 0.25; however, in comparison to the other results given in Table 3.6, it is apparent that again, fear does play a significant role in one's decision to get screened.

Finally, one last example is that proficiency in the use of the standard English language has a small effect on the quality of physician patient communication if correct information failed to be exchanged. This is clearly illustrated via scenarios A, B, and C given in Table 3.7.

Factor variables of interest varied throughout the validation trials:

- Number of accessible primary care physicians (PCPs)
- Number of screening facilities
- Physician awareness of screening guidelines (PCP Awareness)
- Physician compliance with screening guidelines (PCP Compliance)
- Level of fear of process (fear of process)
- Level of fear of results (fear of results)
- Level of concern (concern)
- Level of Education (Education)
- Correctness of info exchange (info exchange)
- Level of standard English spoken and understood (English)

Table 3.3A: Examining Increase in PCPs and Screening Facilities

*** *Variable Conditions*: PCP Awareness = 0.7, PCP Compliance = 0.6, fear of process = 0.6
fear of results = 0.5, concern = 0.8, Education = 0.53, info exchange = 1, English = 1 ***

Note: For those entries with Expo(α, *i*), α = mean, and UNIF(a, b, *j*), *i* and *j* are random number streams

Screening Level rounded up to the nearest integer

<table>
<tr><td colspan="2">Scenario A) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12
Max Arrivals: 25 (Arrivals to Rural Area)
Screening Facility Arrival Rate: Every 180 days
Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2
Run Length: 400 days</td></tr>
<tr><td colspan="2">Results:</td></tr>
<tr><td>Screening Level</td><td>Screening Rate</td></tr>
<tr><td>784524</td><td>0.3493</td></tr>
<tr><td colspan="2">Scenario B) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12
Max Arrivals: 25 (Arrivals to Urban Area)
Screening Facility Arrival Rate: Every 180 days
Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2
Run Length: 400 days</td></tr>
<tr><td colspan="2">Results:</td></tr>
<tr><td>Screening Level</td><td>Screening Rate</td></tr>
<tr><td>751911</td><td>0.3348</td></tr>
<tr><td colspan="2">Scenario C) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12
Max Arrivals: 36 (Arrivals to Rural Area)
Screening Facility Arrival Rate: Every 180 days
Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2
Run Length: 730 days</td></tr>
<tr><td colspan="2">Results:</td></tr>
<tr><td>Screening Level</td><td>Screening Rate</td></tr>
<tr><td>841334</td><td>0.3692</td></tr>
<tr><td colspan="2">Scenario D) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12
Max Arrivals: 36 (Arrivals to Urban Area)
Screening Facility Arrival Rate: Every 180 days
Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2
Run Length: 730 days</td></tr>
<tr><td colspan="2">Results:</td></tr>
<tr><td>Screening Level</td><td>Screening Rate</td></tr>
<tr><td>769292</td><td>0.3376</td></tr>
<tr><td colspan="2">Scenario E) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12
Max Arrivals: 54 (Arrivals to Rural Area)
Screening Facility Arrival Rate: Every 180 days
Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2
Run Length: 1095 days</td></tr>
</table>

Results:	
Screening Level	Screening Rate
937582	0.4115
Scenario F) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 54 (Arrivals to Urban Area) Screening Facility Arrival Rate: Every 180 days	
Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2	
Run Length: 1095 days	
Results:	
Screening Level	Screening Rate
787536	0.3456

Table 3.3 B: Examining Increase in PCPs and Screening Facilities

*** *Variable Conditions*: PCP Awareness = 1, PCP Compliance = 1, fear of process = 0
fear of results=0, concern = 1, Education = 0.53, info exchange = 1, English = 1 ***
Note: For those entries with Expo(α, *i*), α = mean, and UNIF(a, b, *j*), *i* and *j* are random number streams
Screening Level rounded up to the nearest integer

Scenario A) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 25 (Arrivals to Rural Area) Screening Facility Interarrival Time: Expo(180,2) days Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2 Run Length: 400 days	
Results:	
Screening Level	Screening Rate
924411	0.4116
Scenario B) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 25 (Arrivals to Urban Area) Screening Facility Interarrival Time: Expo(180,2) days Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2 Run Length: 400 days	
Results:	
Screening Level	Screening Rate
861335	0.3835
Scenario C) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 36 (Arrivals to Rural Area) Screening Facility Interarrival Time: Expo(180,2) days Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2 Run Length: 730 days	
Results:	
Screening Level	Screening Rate
1066551	0.4681
Scenario D) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 36 (Arrivals to Urban Area) Screening Facility Interarrival Time: Expo(180,2) days Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2 Run Length: 730 days	

Results:	
Screening Level	Screening Rate
903137	0.3963
Scenario E) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 54 (Arrivals to Rural Area)	
Screening Facility Interarrival Time: Expo(180,2) days Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2 Run Length: 1095 days	
Results:	
Screening Level	Screening Rate
1285254	0.564
Scenario F) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 54 (Arrivals to Urban Area) Screening Facility Interarrival Time: Expo(180,2) days Entities per Arrival: UNIF(5,10,4), Max Arrivals: 2 Run Length: 1095 days	
Results:	
Screening Level	Screening Rate
947014	0.4156

Table 3.4: Examining Increase in PCPs
(zero increase in screening facilities)

*** *Variable Conditions*: PCP Awareness = 1, PCP Compliance = 1, fear of process = 0
fear of results = 0, concern = 1, Education = 0.53, info exchange = 1, English = 1***
Note: Demand Level and Screening Level rounded up to the nearest integer

Scenario A) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 25 (Arrivals to Rural Area) Run Length: 400 days		
Results:		
Demand Level	Screening Level	Screening Rate
392928	875381	0.3898
Scenario B) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 25 (Arrivals to Urban Area) Run Length: 400 days		
Results:		
Demand Level	Screening Level	Screening Rate
270473	857373	0.3818
Scenario C) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 36 (Arrivals to Rural Area) Run Length: 730 days		
Results:		
Demand Level	Screening Level	Screening Rate
599566	1038584	0.4558
Scenario D) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 36 (Arrivals to Urban Area) Run Length: 730 days		

Results:		
Demand Level	Screening Level	Screening Rate
330189	902377	0.396
Scenario E) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 54 (Arrivals to Rural Area) Run Length: 1095 days		
Results:		
Demand Level	Screening Level	Screening Rate
952230	1220522	0.5356
Scenario F) PCP Arrival Rate: Every 20 days , Entities per Arrival: 12 Max Arrivals: 54 (Arrivals to Urban Area) Run Length: 1095 days		
Results:		
Demand Level	Screening Level	Screening Rate
392665	946415	0.4153

Table 3.5: Examining PCP Awareness and Compliance (zero increase in PCPs and screening facilities)

*** *Variable Conditions*: fear of process = 0, fear of results = 0, concern = 1, Education = 0.53 info exchange = 1, English = 1 ***

Note: Screening Level rounded up to the nearest integer

Scenario A) PCP Awareness = 0.4, PCP Compliance = 0.25 Run length: 400 days	
Results:	
Screening Level	Screening Rate
728863	0.3245
Scenario B) PCP Awareness = 1, PCP Compliance = 0.25 Run length: 400 days	
Results:	
Screening Level	Screening Rate
762037	0.3393
Scenario C) PCP Awareness = 1, PCP Compliance = 0.8 Run length: 400 days	
Results:	
Screening Level	Screening Rate
832249	0.3706
Scenario D) PCP Awareness = 1, PCP Compliance = 1 Run length: 400 days	
Results:	
Screening Level	Screening Rate
857373	0.3818

Table 3.6: Examining fear of process, fear of results, and concern (zero increase in PCPs and screening facility capacities)

*** *Variable Conditions*: PCP Awareness = 1, PCP Compliance = 1, Education = 0.53 info exchange = 1, English = 1 ***

Note: Screening Level rounded up to the nearest integer

Scenario A) fear of process = 0.9, fear of results = 0.9, concern = 0.25 Run length: 400 days	
Results:	
Screening Level	Screening Rate
709449	0.3159
Scenario B) fear of process = 0.2, fear of results = 0.2, concern = 0.25 Run length: 400 days	
Results:	
Screening Level	Screening Rate
761289	0.339
Scenario C) fear of process = 0.2, fear of results = 0.2, concern = 0.7 Run length: 400 days	
Results:	
Screening Level	Screening Rate
810761	0.361
Scenario D) fear of process = 0.2, fear of results = 0.2, concern = 0.95 Run length: 400 days	
Results:	
Screening Level	Screening Rate
837769	0.3730
Scenario E) fear of process = 0.9, fear of results = 0.9, concern = 0.95 Run length: 400 days	
Results:	
Screening Level	Screening Rate
786741	0.3503

Table 3.7: Examining English and info exchange
(zero increase in both PCP and screening facility capacities)

*** *Variable Conditions*: PCP Awareness = 1, PCP Compliance = 1, fear of process = 0
fear of results = 0, concern = 1, Education = 0.53 ***
Note: Screening Level rounded up to the nearest integer

Scenario A) English = 0.4, info exchange = 0.3 Run length: 400 days	
Results:	
Screening Level	Screening Rate
737141	0.3282
Scenario B) English = 1, info exchange = 0.3 Run length: 400 days	
Results:	
Screening Level	Screening Rate
781712	0.3481
Scenario C) English = 1, info exchange = 0.8 Run length: 400 days	
Results:	
Screening Level	Screening Rate
836295	0.3724

4 SIMULATION EXPERIMENTS, RESULTS, AND ANALYSIS

The previous chapter introduced the simulation model and its varying components used to simulate the colon cancer care (CCC) system. This chapter introduces different intervention schemes, the simulation experiments that will test the effectiveness of the intervention schemes, and then gives the results from the experiments and further performance analysis.

4.1 Intervention

As mentioned earlier in Chapter 1, there exist several barriers in accessing colon cancer care (CCC). Many of these barriers, however, can be alleviated by implementing certain intervention schemes. In general, several intervention schemes can be grouped under the following categories: improving health care delivery and resource capacity, increasing patient adherence, improving the physician role in the CCC system, and increasing overall public awareness.

The delivery of health care is an important factor in the CCC system and its improvement can help increase the screening rate. In general, a limited capacity in a regular source of health care is associated with lower rates of cancer screening, and this is usually more prominent in rural areas with HPSA designations (Georgetown University - Institute for Health Care Research and Policy 2003;National Cancer Policy Board, Institute of Medicine, and National Research Council 1999;United States General Accounting Office 2003). Therefore, for this study, a method of intervention is to increase the number of accessible primary care physicians (PCPs) in rural NC. In addition, an increase in the number of screening facilities is used as a means of intervention in an effort to decrease the average distance to a facility, and increase the overall capacity for screening.

Patient adherence has an important role in the CCC system. Although awareness is significant in screening, it becomes futile if the patient does not adhere to the screening recommendations provided by the health care professional. As mentioned above, several factors contribute to the patient neglecting the screening recommendations. One of the most significant factors is the emotional barrier. Many times patients have a fear of the screening process and are reluctant to receiving the results of their screening tests. In addition, some patients have an overall careless attitude towards the general notion of getting screened. An intervention scheme to help break down these emotional barriers is to incorporate some type of social support network for the patient (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999). This social support network could be community based or simply the family of the patient. In fact, the family unit of the patient impacts the health and the health behavior of the patient; and the health professional should take advantage of how family members can be of help and work with them in encouraging the patient to follow through with the physician's orders (Dona R.Falvo 1994).

Furthermore, another barrier to patient adherence is the common oblivion. In this study, the incorporation of a patient reminder system is used as the method of intervention. This patient reminder system can be rendered in a couple of ways, such as via mail or telephone communication (Dona R.Falvo 1994;National Cancer Policy Board, Institute of Medicine, and National Research Council 1999).

As mentioned previously in Chapter 1, the role of the physician is critical in the CCC system. In this study, three intervention schemes involving the role of the physician are examined. One means for improving the screening rate for example is to increase the awareness of PCPs, since they help serve as the purveyors of information regarding the importance in screening. In particular, physician reminder systems can be instituted to help educate and remind physicians of the screening guidelines (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999). Furthermore, once the PCP is aware, it is even more important that he/she comply with the screening regulations. Therefore, a simple intervention scheme is to increase PCP compliance. Finally, when the PCP complies with the screening regulations, it is his/her obligation to effectively communicate the information to the patient. In some cases, there is a poor quality of physician-patient communication (National Cancer Policy Board, Institute of Medicine, and National Research Council 1999). Many times the quality of information given to the patient and how well he/she understands it affects the overall quality of the physician-patient communication. In this study, the intervention scheme used in an effort to improve the physician-patient communication is the inclusion of some type of confirmation of information. In other words, the physician will ensure the patient understands what has been relayed to him/her. This understanding could possibly result from a clarification of statements, and a clarification of medical terms to avoid misunderstandings.

Moreover, another intervention scheme examined in this study is the incorporation of public awareness. Many times public awareness can occur through multimedia educational intervention (National Cancer Policy Board, Institute of

Medicine, and National Research Council 1999). Examples of multimedia intervention include television ads, spokespersons, such as Katie Couric, the renowned co-anchor of the news morning show "Today", magazine articles, radio advertisements, and the Internet.

The intervention schemes mentioned above are incorporated in the simulation model in different ways, most being represented as variables. The health care delivery intervention schemes, including the increase in PCP supply in rural NC, and an increase in the number of screening facilities, are implemented in the simulation model with the use of the simulation "create" module.

The patient adherence intervention schemes are represented as variables. In particular, there is a social support network variable, and a patient reminder system variable, both of whose descriptions are given in Table 3.1. The intervention methods involving an improvement in the role of the physician are represented as variables as well. There is a variable for PCP compliance, discussed earlier in Chapter 3. There are also a physician reminder system and confirmation of communication variables, both of whose descriptions are given in Table 3.1. Finally, the multimedia intervention is also represented as a variable, and its description is given in Table 3.1.

4.2 Performance Measurements

Several performance measures are used in this study to test and evaluate the effectiveness of the intervention schemes explained above, over a simulation run time of 1095 days (3 years). User-defined response variables in Arena, some of which are mentioned in Sections 3.6 and 3.7, are utilized in the various simulation experiments.

These variables include: Final Awareness Level, Final Demand Level, Screening Level at Time (Day) 365, Screening Level at Time (Day) 730, Final Screening Level, and Final Screening Rate. The purpose in having some of these responses in addition to the most significant, the screening level, is that some of the intervention schemes directly affect the awareness level, and consequently the demand level, while some others just directly affect the demand level. In addition, the screening level at times 365 and 730 are captured to examine if and how these intervention schemes affect the screening level annually.

4.3 Simulation Experiments and Preliminary Results

4.3.1 Base Case

The base case is simply the scenario before any intervention scheme has been implemented. As mentioned earlier in Section 4.2, the simulation run length is 1095 days or 3 years. This simulation run length has been selected partly based on execution time constraints, and because there are data readily available for the screening rates for 2003 (American Cancer Society 2004a), that can be utilized as a basis for comparison for the simulation results. According to the American Cancer Society, the screening rate for the NC 50 and older population in the beginning of 2003 was on average ~35.1%. With this known, certain variable values have been selected for the base case so the base case scenario to reflect "reasonable results". The base case has a zero increase in resource capacity along with the following initial variable values:

- Physician awareness of screening guidelines (PCP Awareness) = 0.70
- Physician compliance with screening guidelines (PCP Compliance) = 0.60

- Level of fear of process = 0.75
- Level of fear of results = 0.55
- Level of concern = 0.70
- Correctness of info exchange = 0.70
- Level of standard English spoken and understood = 0.75

Notice that the above variables have not been pre-calculated as with the other variables mentioned in Section 3.5, where there are data available to do so. However, the above values have been chosen to reasonably reflect the different dynamics of the CCC system and more importantly, to yield reasonable results reflecting the screening level at the beginning of year 2003 without any intervention. The results of the base case scenario are given below. Please note that these are results obtained after one replication. Only one replication is necessary because there is no randomness involved.

Table 4.1: Results for Base Case Scenario
** All Results ≥ 1 have been rounded up to the nearest integer**

Awareness Level	Demand Level	Screening Level at Time 365	Screening Level at Time 730	Final Screening Level	Final Screening Rate
554162	99743	716355	732001	743159	0.3261

From Table 4.1, the final screening rate is ~ 32.6%. It is assumed that this is a reasonable figure considering no intervention has taken place. Although, it is ~3% less than 35.1%, it is also assumed that intervention has been taken place in the "real world" to increase the screening level by ~5% (recall, in 2000, ACS reported the screening rate to be ~30.45%). Overall, the base case scenario gives a good starting point for studying intervention.

4.3.2 Examining Resource Capacity

An improvement in PCP accessibility and an increase in the number of screening facilities were examined through capacity changes. In an effort to get a general idea of how increasing the number of rural PCPs affects the overall performance measures, a couple of scenarios were tested. The two scenarios differ in the rate at which PCPs arrived to the CCC system. With each rate, however, the simulation model was designed to cause the number of new PCPs that entered the system to approximate 660. This figure is based on the average increase in PCPs in NC from year to year (2003c). In addition, both scenarios incorporate different levels representing the percentage of PCPs that are actually designated to rural NC. In particular, the levels are 10%, 30%, 50%, 80%, and 100%. The results from these scenarios are given below in Table 4.2. Note that because randomness is involved in the rate at which PCPs entered the CCC system, several replications are required to obtain average values for the performance measures. In this case, 20 replications were run for the simulation experiment.

Table 4.2A: Results for Increase in Rural PCP Accessibility
Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream
** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO				RESULTS					
	PCP Interarrival Time (in days) Distribution	Number of PCPs per Arrival	Percentage of New PCPs designated for NC Rural Area	Average Awareness Level	Average Demand Level	Average Screening Level at Time 365	Average Screening Level at Time 730	Average Final Screening Level	Average Final Screening Rate
A	Expo(30,3)	20	10%	594069	107788	717888	735260	748529	0.3285
B	Expo(30,3)	20	30%	68913	126673	720995	742523	761086	0.334
C	Expo(30,3)	20	50%	802308	150379	724267	750823	776503	0.3408
D	Expo(30,3)	20	80%	1034790	198692	729521	765436	806262	0.3538
E	Expo(30,3)	20	100%	1246872	243215	733128	777052	831990	0.3651

Table 4.2B: Results for Increase in Rural PCP Accessibility
Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream
** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO				RESULTS					
	PCP Interarrival Time (in days) Distribution	Number of PCPs per Arrival	Percentage of New PCPs designated for NC Rural Area	Average Awareness Level	Average Demand Level	Average Screening Level at Time 365	Average Screening Level at Time 730	Average Final Screening Level	Average Final Screening Rate
A	Expo(60,3)	30	10%	589419	106816	717793	735028	747945	0.3282
B	Expo(60,3)	30	30%	669907	123098	720659	741623	758837	0.333
C	Expo(60,3)	30	50%	767460	143012	723701	749085	771926	0.3388
D	Expo(60,3)	30	80%	957266	182181	728484	762057	796670	0.3496
E	Expo(60,3)	30	100%	1124157	216964	732030	772292	817606	0.3588

Tables 4.2A and 4.2B show that in general, increasing the number of accessible PCPs in rural NC does improve the screening rate; all of the results are > 32.6%. Also, notice, that there is a general increase in the awareness level as well as the demand level.

At this point, analysis, regarding resource capacity in the context of PCPs will employ the scenarios in Table 4.2B. Furthermore, regarding these chosen alternatives,

Table 4.2B shows that as the percentage of new rural PCPs increases, the screening level also increases. However, because randomness is involved, it needs to be shown that with each percentage increase in the number of rural PCPs, there is an increase in the screening level that is statistically significant. The Output Analyzer, a software program available with Arena, is used to conduct a statistical comparison among the various scenarios. The Output Analyzer provides the tools to perform a paired t-test to examine statistical differences among the scenarios of interest.

First, the Output Analyzer is used to conduct a paired t-test to determine if the difference in the mean screening levels between alternatives B and A (in Table 4.2B) is statistically different at the 0.05 significance level. The 95% confidence interval generated by the output analyzer is shown below. From Figure 4.1, it is clear that zero is not included in the 95% confidence interval, and therefore, alternative B is statistically different and greater than alternative A in reference to the screening level.

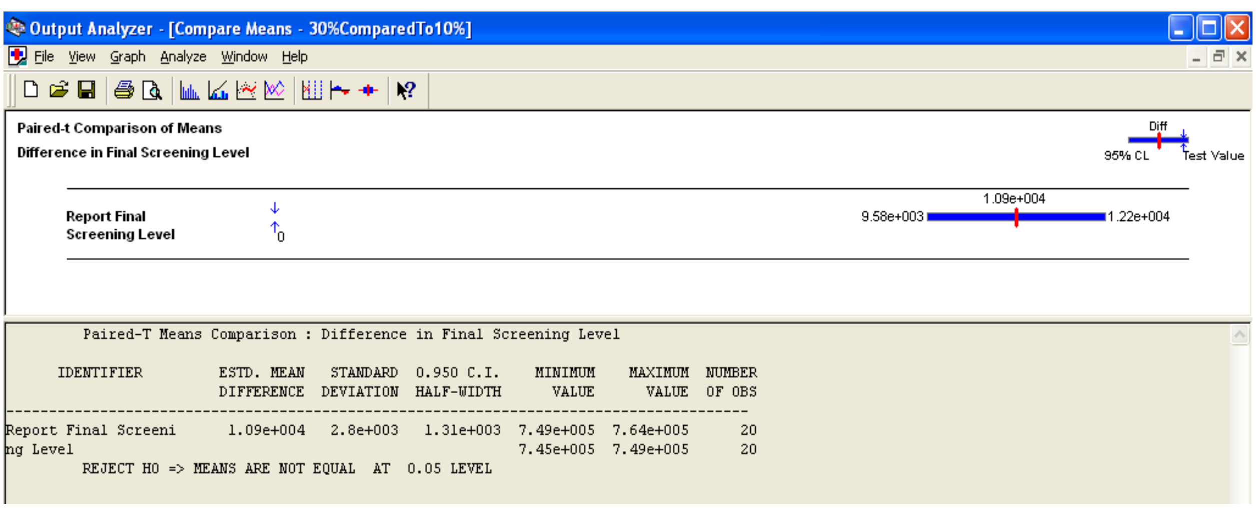

Figure 4.1: 95% Confidence Interval Results for difference in mean screening levels for Scenarios A and B in Table 4.2B

Furthermore, similar paired t-tests are performed for scenarios C and B, scenarios D and C, and scenarios E and D. The figures illustrating the 95% confidence interval and other results are below. Notice that all of the figures from Figure 4.1 through Figure 4.4 show that each percentage increase in the rural NC PCP population yields a statistically different and higher value in the screening level. Again, as in Figure 4.1, none of the 95% confidence intervals include zero. Therefore, it can be concluded, at least for the cases where the interarrival rate is described in Table 4.2B, an increase in the number of accessible NC rural PCPs is effective in increasing the screening level, and thus, the screening rate.

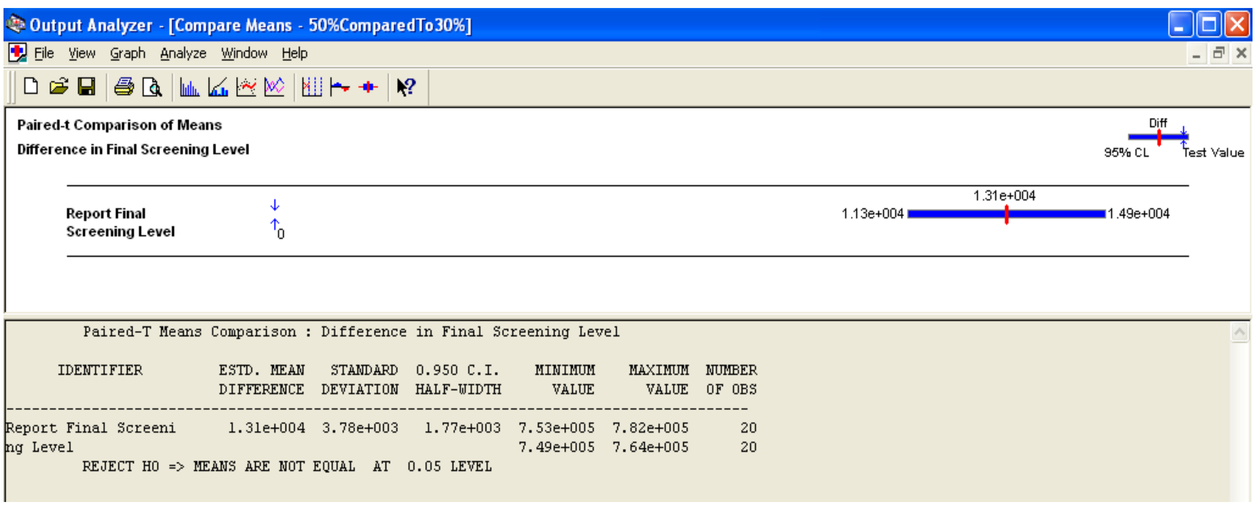

Figure 4.2: 95% Confidence Interval Results for difference in mean screening levels for Scenarios B and C in Table 4.2B

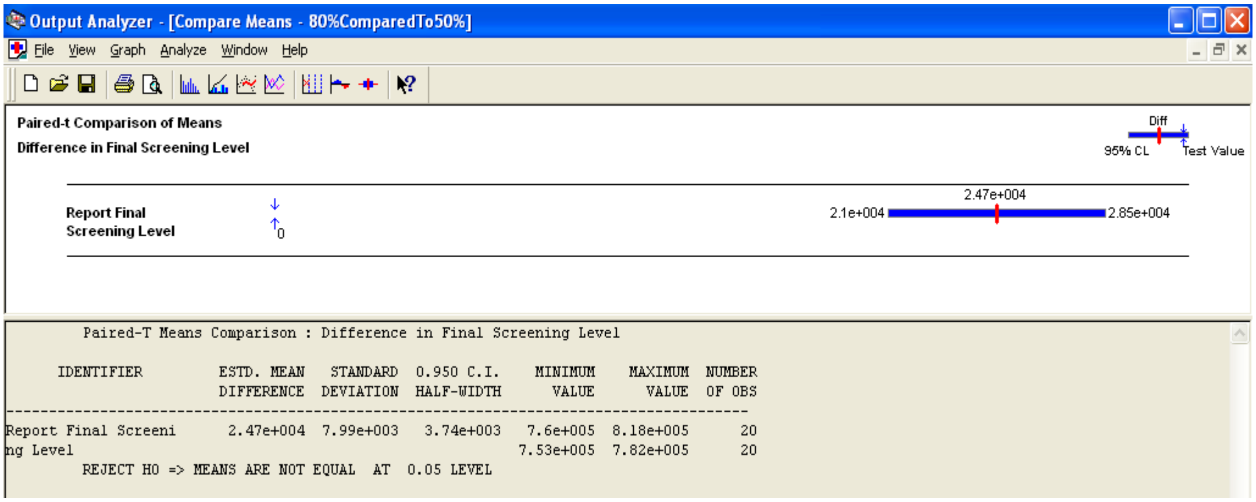

Figure 4.3: 95% Confidence Interval Results for difference in mean screening levels for Scenarios C and D in Table 4.2B

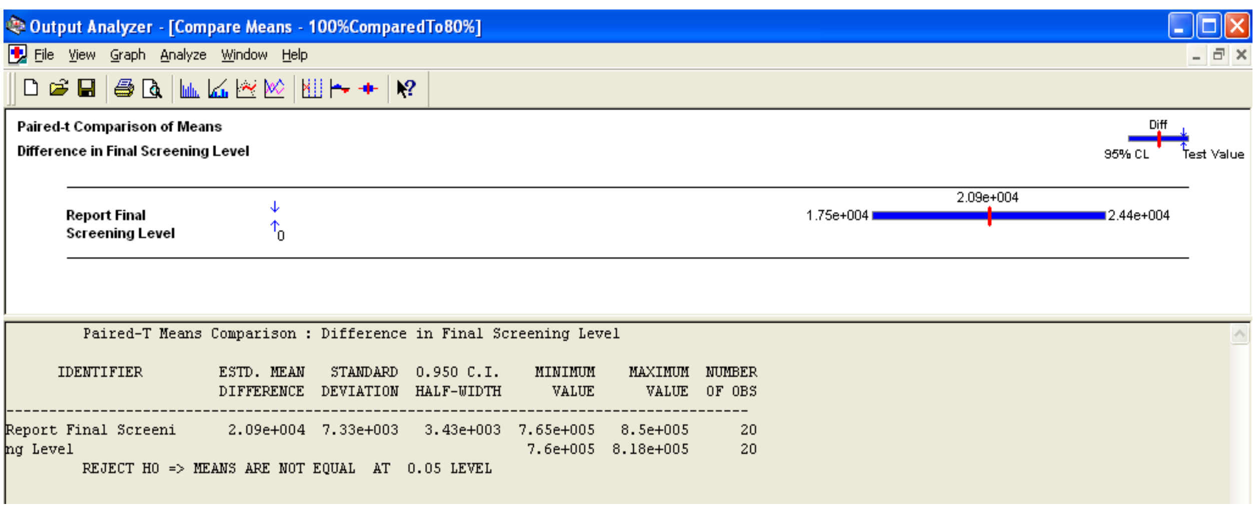

Figure 4.4: 95% Confidence Interval Results for difference in mean screening levels for Scenarios D and E in Table 4.2B

In addition to examining an increase in rural PCPs, an increase in the number of screening facilities was examined. The two alternatives investigated differ in the rate at which new facilities "arrive" to the CCC system. Also, for these alternatives, randomness was incorporated in the interarrival time of the screening facilities. The details of each alternative and the associated results, after running 20 replications, are given below in Table 4.3.

Table 4.3: Results for Increase in Screening Facilities

Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream

** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO				RESULTS					
	Screening Facility Interarrival Time (in days) Distribution	Number of Screening Facilities per Arrival	Average Final Increase in Number of Screening Facilities	Average Awareness Level	Average Demand Level	Average Screening Level at Time 365	Average Screening Level at Time 730	Average Final Screening Level	Average Final Screening Rate
A	Expo(365,2)	1	4	554162	99743	717076	732189	743354	0.32622
B	Expo(365,2)	2	8	554162	99743	717443	732196	743370	0.32623

From Table 4.3, it can be seen that there is a slight increase in the final screening level, as well as the screening levels at times 365 and 730, by having more accessible screening facilities. However, there is not much improvement between alternatives A and B in Table 4.3. Also, notice how an increase in screening facilities does not affect the awareness level or the demand level. This result, of course, is reasonable given that the number of screening facilities impacts the congestion level, and thus the number of people who are able to get screened. Figure 4.5 below gives the results of a paired t-test which has been performed to determine if there is a statistical difference in the screening level between that of alternative A and alternative B in Table 4.3.

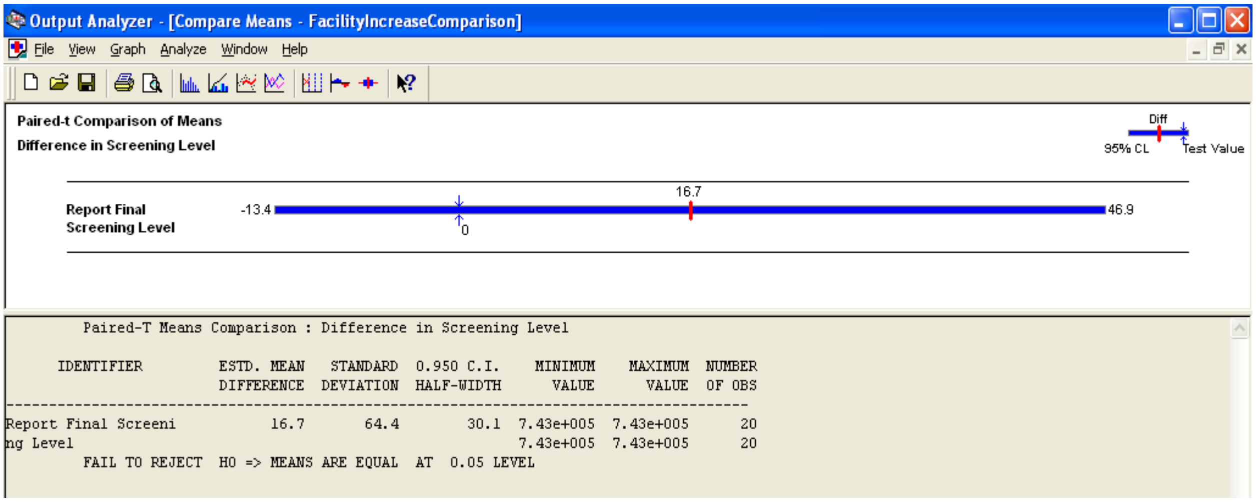

Figure 4.5: 95% Confidence Interval Results for difference in mean screening levels for Scenarios A and B in Table 4.3

Figure 4.5 illustrates the difference in screening levels for scenarios A and B in Table 4.3 is not statistically significant, since zero is included in the 95% confidence interval.

Moreover, from Table 4.3 and Figure 4.5, it seems that a great increase in the number of screening facilities is not that effective. However, this result could be different if there is an increase in the number of accessible PCPs, and hence an increase in the demand level. The following tables give the results for combining the scenarios in Tables 4.2B and 4.3. The results are those obtained after running 20 replications.

Table 4.4A: Results for Increase in PCPs and Screening Facilities

Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream

** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO		RESULTS					
PCP Interarrival Time (in days) Distribution : Expo (60,3) Number of PCPs per Arrival: 30 Screening Facility Interarrival Time (in days) Distribution: Expo(365,2) Number of Screening Facilities per Arrival: 1 Average Final Increase in Number of Screening Facilities: 27	Percentage of New PCPs designated for NC Rural Area	Average Awareness Level	Average Demand Level	Average Screening Level at Time 365	Average Screening Level at Time 730	Average Final Screening Level	Average Final Screening Rate
A	10%	589419	106816	718489	735151	748085	0.3283
B	30%	669907	123098	721481	741851	759131	0.3331
C	50%	767460	143012	724753	749391	772423	0.339
D	80%	957265	182181	729806	762651	797871	0.3501
E	100%	1124157	216964	733735	773214	819929	0.3598

Table 4.4B: Results for Increase in PCPs and Screening Facilities

Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream

** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO		RESULTS					
PCP Interarrival Time (in days) Distribution : Expo (60,3) Number of PCPs per Arrival: 30 Screening Facility Interarrival Time (in days) Distribution: Expo(365,2) Number of Screening Facilities per Arrival: 2 Average Final Increase in Number of Screening Facilities: 31	Percentage of New PCPs designated for NC Rural Area	Average Awareness Level	Average Demand Level	Average Screening Level at Time 365	Average Screening Level at Time 730	Average Final Screening Level	Average Final Screening Rate
A	10%	589419	106816	718973	735273	748210	0.3284
B	30%	669907	123098	722019	741883	759175	0.3332
C	50%	767460	143012	725586	749607	772699	0.3391
D	80%	957265	182181	730689	763063	798561	0.3505
E	100%	1124157	216964	735194	773872	821209	0.3604

Between each corresponding alternative in Table 4.4A and Table 4.4B, there is still very little change in the screening level, even though there has been an increase in the demand level. This change further shows that an improvement in the number of screening facilities, such as going from an average increase of 4 facilities to an average increase of 8 facilities, is not that effective.

4.3.3 Examining Patient Adherence Intervention

This section examines patient adherence interventions. As discussed in Section 4.1, adherence focuses on social support networks and patient reminder systems as a means for intervention. Both intervention schemes are implemented in the simulation model in an effort to capture "realistic" mechanisms. It is assumed, for instance, that if the general health care system recognizes how family support increases patient adherence, then an increased effort will be made to enforce family support where it is lacking. The same type of logic applies to the effectiveness of patient reminder systems, which in turn helps to eliminate "no shows". The intervention variables, social support network and patient reminder system are improved dynamically in the simulation model. The results after running one replication are reported in Table 4.5 and Table 4.6. Only one replication is needed because randomness is not incorporated in these scenarios.

Table 4.5: Results for Inclusion of Social Support Network
** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO		RESULTS					
Annual percentage **decrease** in Levels of Fear	Annual percentage **increase** in Level of Concern	Awareness Level	Demand Level	Screening Level at Time 365	Screening Level at Time 730	Final Screening Level	Final Screening Rate
5%	5%	554162	108793	718918	736252	749411	0.3289
5%	8%	554162	112322	719867	737908	751899	0.33
5%	10%	554162	114726	720500	738972	753543	0.3307
5%	12%	554162	117171	721134	739923	755089	0.3314
10%	5%	554162	112017	719897	737887	751698	0.3299
10%	8%	554162	115546	720847	739392	754032	0.3309
10%	10%	554162	117950	721480	740374	755590	0.3316
10%	12%	554162	120395	722113	741563	757341	0.3324
20%	5%	554162	118056	721857	740735	755648	0.3316
20%	8%	554162	121584	722807	742186	757922	0.3326
20%	10%	554162	123988	723440	743583	759912	0.3335
20%	12%	554162	126433	724073	744522	761397	0.3341
30%	5%	554162	123584	723817	743840	759624	0.3334
30%	8%	554162	127113	724766	745509	762083	0.3344
30%	10%	554162	129517	725399	746529	763727	0.3352
30%	12%	554162	131962	726032	747554	765300	0.3359

Table 4.6: Results for Inclusion of Patient Reminder System
** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO	RESULTS					
Annual percentage decrease in percentage no show	Awareness Level	Demand Level	Screening Level at Time 365	Screening Level at Time 730	Final Screening Level	Final Screening Rate
5%	554162	99743	717262	733562	745402	0.3271
10%	554162	99743	718169	735089	747543	0.3281
20%	554162	99743	719983	738043	751534	0.3298
30%	554162	99743	721797	740863	755162	0.3314
40%	554162	99743	723611	743548	758455	0.3328

Tables 4.5 and 4.6 show that the intervention schemes used to improve patient adherence are effective in increasing the screening level; all final screening rates are in fact greater than 32.61%, which is the final screening level for the base case. Notice also that neither

of the intervention schemes in this category directly affects the awareness level. This occurrence exists because patient adherence assumes the patient is already aware, and therefore any intervention to improve adherence will either affect the demand level directly, or simply the screening level, as is the case for patient reminder systems.

4.3.4 Examining Physician Intervention

As noted in Section 4.1, another group of intervention is related to improving the role of the physician. The improvement in PCP awareness, PCP compliance, both PCP awareness and compliance, and the improvement in quality of physician patient communication was examined in this study. It is important to note how these intervention schemes were incorporated in a way to model "realistic" effects. For example, PCP awareness increases dynamically. This change happens because it is reasonable to think that as PCPs become aware, it is very likely that more PCPs will become aware over time; in essence, it can be similar to the domino effect. Likewise, this occurrence is reasonable as the communication between the physician and the patient improves. It is assumed that this occurrence is not as likely, however, for PCP compliance in that the means for a physician to comply are more individually based. Therefore, the intervention regarding PCP compliance calls for a static increase in PCP compliance, rather than dynamic (static in reference to a single increase in the level of PCP compliance, effective for the whole simulation run). Table 4.7 through Table 4.10, below, give the results for these intervention schemes, respectively. The results have been generated after one replication, since randomness is not involved for these particular scenarios.

Table 4.7: Results for Increase in PCP Awareness

** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO	RESULTS					
Annual percentage increase in PCP Awareness	Awareness Level	Demand Level	Screening Level at Time 365	Screening Level at Time 730	Final Screening Level	Final Screening Rate
5%	567339	102269	717059	733089	744818	0.3269
8%	575488	103837	717481	733924	746018	0.3274
10%	581024	104905	717762	734224	746578	0.3276
12%	586644	105992	718043	734626	747247	0.3279

Table 4.8: Results for Increase in PCP Compliance

** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO	RESULTS					
Static increase in Level of PCP Compliance	Awareness Level	Demand Level	Screening Level at Time 365	Screening Level at Time 730	Final Screening Level	Final Screening Rate
0.10	615736	110826	721058	738514	750908	0.3295
0.20	677309	121909	725761	745041	758707	0.333
0.30	738883	132991	730464	751497	766364	0.3363
0.40	800456	144074	735167	757534	773707	0.3395

Table 4.9: Results for Increase in PCP Awareness and Compliance
** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO		RESULTS					
Annual percentage increase in PCP Awareness	Static increase in Level of PCP Compliance	Awareness Level	Demand Level	Screening Level at Time 365	Screening Level at Time 730	Final Screening Level	Final Screening Rate
5%	0.10	628912	113351	721762	739596	752564	0.3303
5%	0.20	690486	124434	726464	746119	760322	0.3337
5%	0.30	752059	135517	731167	752611	768052	0.3371
5%	0.40	813633	146599	735870	759111	775789	0.3405
8%	0.10	637061	114920	722184	740297	753669	0.3307
8%	0.20	698635	126002	726886	746739	761314	0.3341
8%	0.30	760208	137085	731589	753269	769081	0.3375
8%	0.40	821782	148168	736292	759766	776862	0.3409
10%	0.10	642597	115988	722465	740882	754472	0.3311
10%	0.20	704171	127070	727168	747168	762001	0.3344
10%	0.30	765744	138153	731871	753696	769767	0.3378
10%	0.40	827318	149235	736574	760239	777546	0.3412
12%	0.10	648218	117075	722746	741127	754987	0.3313
12%	0.20	709791	128157	727449	747852	762947	0.3348
12%	0.30	771365	139240	732152	754125	770463	0.3381
12%	0.40	832938	150322	736855	760665	778240	0.3415

Table 4.10: Results for Increase in Quality of Physician Patient Communication
** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO	RESULTS					
Annual percentage Improvement in correctness of information exchange	Awareness Level	Demand Level	Screening Level at Time 365	Screening Level at Time 730	Final Screening Level	Final Screening Rate
5%	577221	104163	717586	734021	746175	0.3275
8%	591482	106907	718325	735389	748187	0.3283
10%	601170	108777	718817	736180	749393	0.3289
12%	611006	110678	719310	736864	750577	0.3294

Tables 4.7 through 4.10 show that all of the intervention schemes involved in improving the role of the physician are effective in increasing the screening level; all yield a screening rate greater than 32.61%. In addition, notice that the awareness level and, as a result, the demand level increase with these respective intervention schemes as well.

4.3.5 Examining Public Awareness Intervention

This section examines the effect of large scale public awareness intervention. An example mentioned in Section 4.1 is multimedia intervention. This intervention scheme was also implemented to yield a dynamic effect. In the context of multimedia intervention, it is likely that as more people become aware, more people will spread the word about the importance in colon cancer screening just because of the great influence of the media; many times what the media popularizes, "goes" in the public eye, especially when a reputable person such as Katie Couric is involved. The table below gives the results for this intervention scheme after running one replication. Again, only one replication is necessary because there is no randomness in this scenario.

Table 4.11: Results for Multimedia Intervention

All Results ≥ 1 have been rounded up to the nearest integer

SCENARIO	RESULTS					
Percentage increase in daily Awareness	Awareness Level	Demand Level	Screening Level at Time 365	Screening Level at Time 730	Final Screening Level	Final Screening Rate
5%	581870	105811	719153	735656	747371	0.328
10%	609578	111879	721951	739240	751517	0.3298
15%	637286	117946	724749	742780	755622	0.3316
20%	664995	124014	727547	746581	760009	0.3335
30%	720411	136149	733142	754055	768593	0.3373
40%	775827	148284	738738	761374	776988	0.341
50%	831243	160419	744120	768645	785376	0.3447

From Table 4.11, it is apparent that multimedia intervention is effective. The large scale increase in public awareness is reflected in the increase in the awareness level, as shown in the table.

4.4 Further Performance Analysis

This section performs additional analysis on results obtained from the various scenarios mentioned in Section 4.3. In this section, particular methods in each intervention category will be examined and compared to one another in greater detail. In addition, the intervention categories as a whole are compared to one another in regards to their average respective effectiveness, relative to the base case scenario results. Furthermore, an overall range for an increase in the screening level will be created based on the results and the analysis performed.

4.4.1 Resource Capacity Intervention Analysis

The following tables and figures give information pertaining to the percentage increase in the awareness level, demand level, and the screening level for the intervention schemes mentioned under Tables 4.2B, 4.3 and 4.4A. Again, the intervention scheme mentioned under Table 4.4B is not considered for further analysis because of its insignificant differences in the screening levels from that of the intervention scheme mentioned under Table 4.4A.

Table 4.12: Percentage Increase in Performance Measures for Scenarios in Table 4.2B

Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream

SCENARIO			RESULTS		
PCP Interarrival Time (in days) Distribution	Number of PCPs per Arrival	Percentage of New PCPs designated for NC Rural Area	Percentage increase in Awareness Level	Percentage increase in Demand Level	Percentage increase in Final Screening Level
Expo(60,3)	30	10%	0.0636	0.0709	0.0064
Expo(60,3)	30	30%	0.2089	0.2342	0.0211
Expo(60,3)	30	50%	0.3849	0.4338	0.0387
Expo(60,3)	30	80%	0.7274	0.8265	0.0720
Expo(60,3)	30	100%	1.0286	1.1752	0.1002

The trend in the increase in the performance measure may be better observed from the following graph. Notice, from Figure 4.6, the trend observed in the increases in the awareness level and demand level with respect to the rural NC PCP percentage are somewhat similar, with the increase in demand being slightly higher. However, there is a much lower increase observed with the screening level. This lower screening level could be due to the fact that since there is a higher demand, there is a higher congestion level, and therefore the time it takes for the demand to actually get screened is generally longer. Also, the factor of “no show” still negatively affects the screening level regardless of the increase for demand in screening.

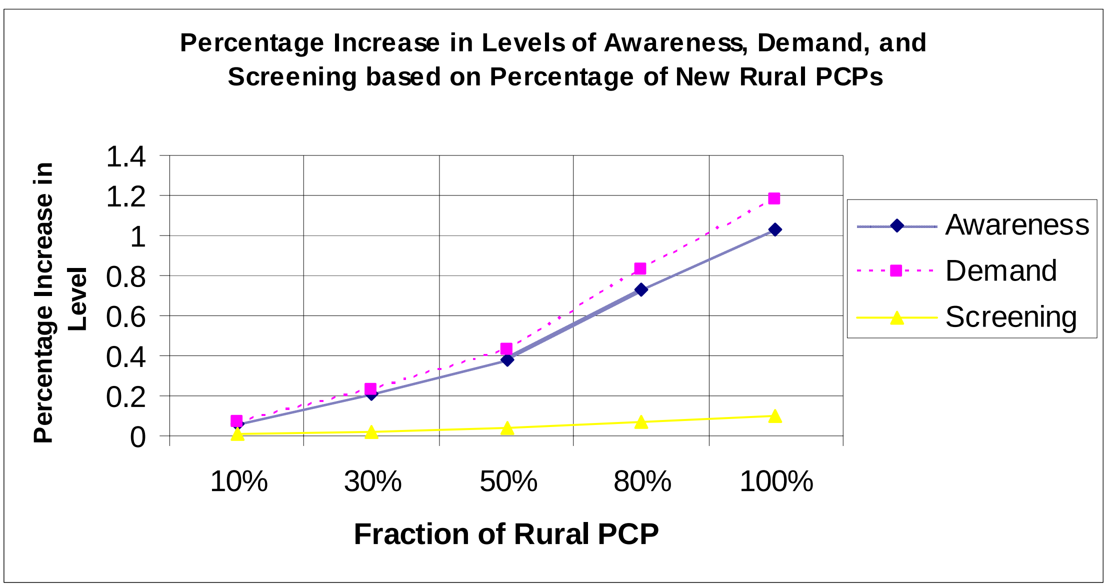

Figure 4.6: Percentage Increase in Performance Measures Relative to Increase in Accessible Rural PCP Intervention

Table 4.13: Avg. Percentage Increase in Performance Measures for Scenarios in Table 4.2B

Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream

SCENARIO			RESULTS		
PCP Interarrival Time (in days) Distribution	Number of PCPs per Arrival	Range for Percentage of New PCPs designated for NC Rural Area	Average Percentage increase in Awareness Level	Average Percentage increase in Demand Level	Average Percentage increase in Final Screening Level
Expo(60,3)	30	10% - 100%	0.4827	0.5481	0.0477

Table 4.14: Percentage Increase in Performance Measures for Scenarios in Table 4.3

Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream

SCENARIO			RESULTS		
Screening Facility Interarrival Time (in days) Distribution	Number of Screening Facilities per Arrival	Average Final Increase in Number of Screening Facilities	Percentage increase in Awareness Level	Percentage increase in Demand Level	Percentage increase in Final Screening Level
Expo(365,2)	1	4	0	0	0.0003
Expo(365,2)	2	8	0	0	0.0003

Again, Table 4.14 reiterates how ineffective increasing the number of accessible screening facilities is when it is the only intervention scheme being executed. From, Table 4.14, it can easily be seen that the average percentage increase in the screening level is near zero.

Table 4.15: Percentage Increase in Performance Measures for Scenarios in Table 4.4A

Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream

SCENARIO		RESULTS		
PCP Interarrival Time (in days) Distribution : Expo (60,3) Number of PCPs per Arrival: 30 Screening Facility Interarrival Time (in days) Distribution: Expo(365,2) Number of Screening Facilities per Arrival: 1 Average Final Number of Screening Facilities: 27	Percentage of New PCPs designated for NC Rural Area	Percentage Increase in Awareness Level	Percentage Increase in Demand Level	Percentage Increase in Final Screening Level
	10%	0.0636	0.0709	0.0066
	30%	0.2089	0.2342	0.0215
	50%	0.3849	0.4338	0.0394
	80%	0.7274	0.8265	0.0736
	100%	1.0286	1.1752	0.1033

Although the values for the percentage increase in the final screening level for the scenarios in Table 4.15 are higher than those for the scenarios in Table 4.12, notice how similar the results are. This similarity may be a result of not having a large enough increase in demand in order to see a significant effect from the additional screening facilities. Figure 4.7, below, also allows this similarity in the values of the performance measures to be observed graphically.

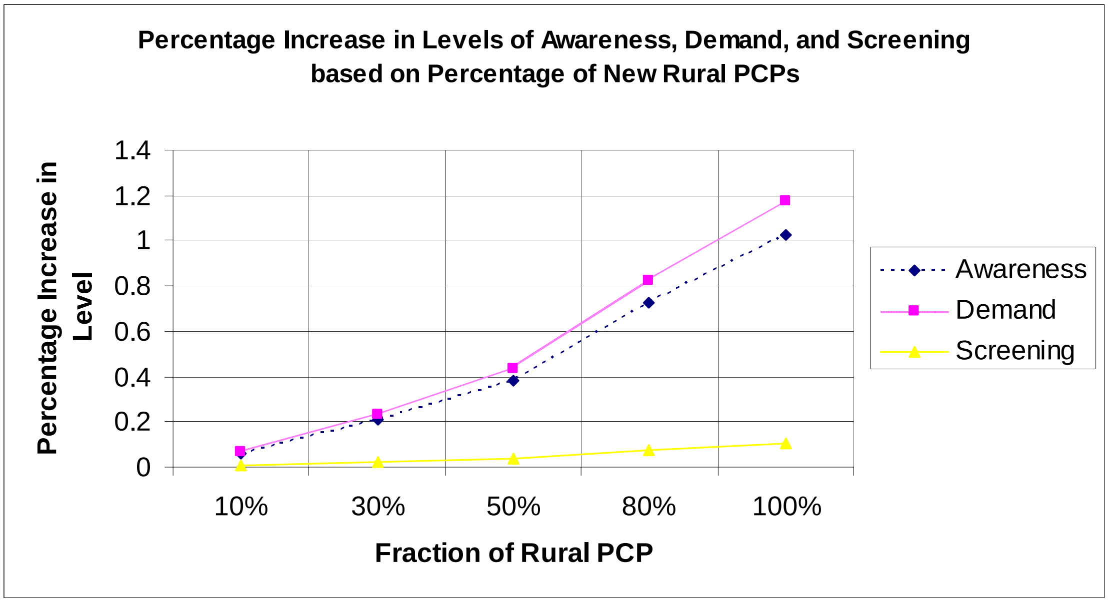

Figure 4.7: Percentage Increase in Performance Measures Relative to Increase in Accessible Rural PCP Intervention and Increase in Number of Screening Facilities

Furthermore, the average percentage increase in the performance measures are given below for the intervention scheme referenced in Table 4.4A.

Table 4.16: Avg. Percentage Increase in Performance Measures for Scenarios in Table 4.4A

Note: For those entries with Expo(α, *i*), α = mean, *i* is the random number stream

SCENARIO		RESULTS		
PCP Interarrival Time (in days) Distribution : Expo (60,3) Number of PCPs per Arrival: 30 Screening Facility Interarrival Time (in days) Distribution: Expo(365,2) Number of Screening Facilities per Arrival: 1 Average Final Number of Screening Facilities: 27	Range for Percentage of New PCPs designated for NC Rural Area	Average Percentage Increase in Awareness Level	Average Percentage Increase in Demand Level	Average Percentage Increase in Final Screening Level
	10% - 100%	0.4827	0.5481	0.0489

Moreover, it can be seen from Tables 4.13, 4.14 and 4.16, that the most effective intervention scheme under this category on average is a combination of increasing the percentage of rural PCPs and increasing the number of screening facilities. However, this combination is only slightly more effective in increasing the screening level than that of solely having an increase in rural PCP capacity (4.9% versus 4.8% respectively).

4.4.2 Patient Adherence Intervention Analysis

The following tables and figures give information pertaining to the percentage increase in the awareness level, demand level, and the screening level for the intervention schemes relative to patient adherence.

Table 4.17: Percentage Increase in Performance Measures for Inclusion of Social Support Network

SCENARIO		RESULTS		
Annual Percentage **Decrease** in Levels of Fear	Annual Percentage **Increase** in Level of Concern	Percentage Increase in Awareness Level	Percentage Increase in Demand Level	Percentage Increase in Final Screening Level
5%	5%	0	0.0907	0.0084
5%	8%	0	0.1261	0.0118
5%	10%	0	0.1502	0.0140
5%	12%	0	0.1747	0.0161
10%	5%	0	0.1231	0.0115
10%	8%	0	0.1584	0.0146
10%	10%	0	0.1825	0.0167
10%	12%	0	0.2071	0.0191
20%	5%	0	0.1836	0.0168
20%	8%	0	0.2190	0.0199
20%	10%	0	0.2431	0.0225
20%	12%	0	0.2676	0.0245
30%	5%	0	0.2390	0.0222
30%	8%	0	0.2744	0.0255
30%	10%	0	0.2985	0.0277
30%	12%	0	0.3230	0.0298

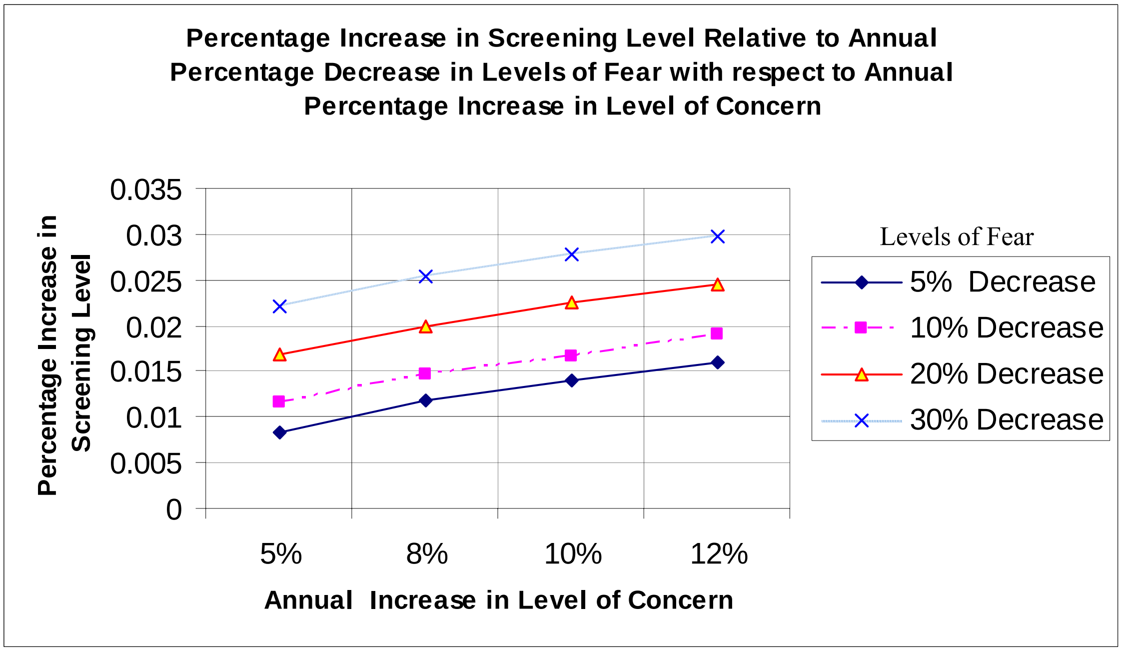

Figure 4.8: Percentage Increase in Screening Level Relative to Percentage Decrease in Fear Levels

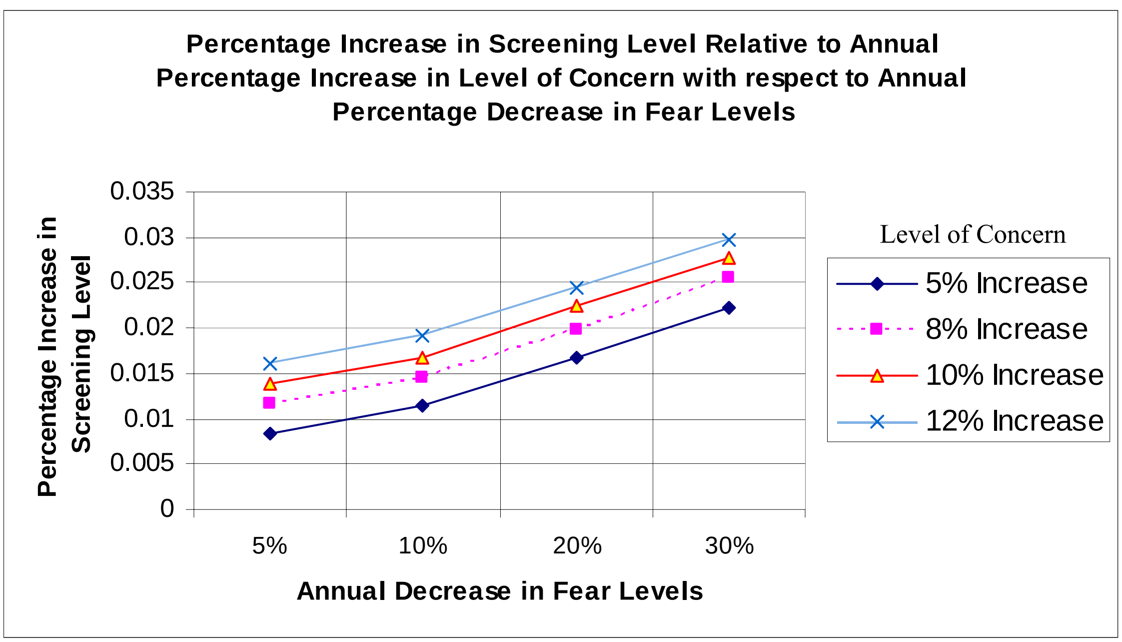

Figure 4.9: Percentage Increase in Screening Level Relative to Percentage Increase in Level of Concern

Figures 4.8 and 4.9 simply illustrate the dynamics in implementing the social support network scheme and improving the levels of fear and level of concern relative to their effect on the screening level. In other words, given that the social support network improves the level of fear and the level of concern at a particular rate, then one can expect a respective improvement in the screening rate based on these figures. In particular, these figures show for a given "improvement" rate in a certain variable level, the rate of increase in screening as the other variable level improves. This allows for a better visual comparison in the trends relative to the effectiveness of the various combinations enlisted in Table 4.17. For instance, one observation is that the rate of percentage increase in the screening level in Figure 4.8 is in general similar for each scenario and therefore irrespective of the percentage by which the levels of fear are decreased. However, higher levels of screening are achieved as the level of concern increases. Furthermore, another observation is that the general rate of improvement in the percentage increase in the screening level is more significant in Figure 4.9 than in Figure 4.8. This is reasonable since there is a greater increase in the annual percentage improvement in the fear levels versus the concern level.

Moreover, the following table includes the average percentage increases in the performance measures for the social support network intervention scheme.

Table 4.18: Avg. Percentage Increase in Performance Measures for Inclusion of Social Support Network

SCENARIO		RESULTS		
Range for Annual Percentage **Decrease** in Levels of Fear	Range for Annual Percentage **Increase** in Level of Concern	Average Percentage Increase in Awareness Level	Average Percentage Increase in Demand Level	Average Percentage Increase in Final Screening Level
5% - 30%	5% - 12%	0	0.2038	0.0188

The next table gives the percentage increase in performance measures resulting from implementing the patient reminder system. This table is also followed by a graph illustrating the respective results.

Table 4.19: Percentage Increase in Performance Measures for Inclusion of Patient Reminder System

SCENARIO	RESULTS		
Annual Percentage Decrease in Percentage No Show	Percentage Increase in Awareness Level	Percentage Increase in Demand Level	Percentage Increase in Final Screening Level
5%	0	0	0.0030
10%	0	0	0.0059
20%	0	0	0.0113
30%	0	0	0.0162
40%	0	0	0.0206

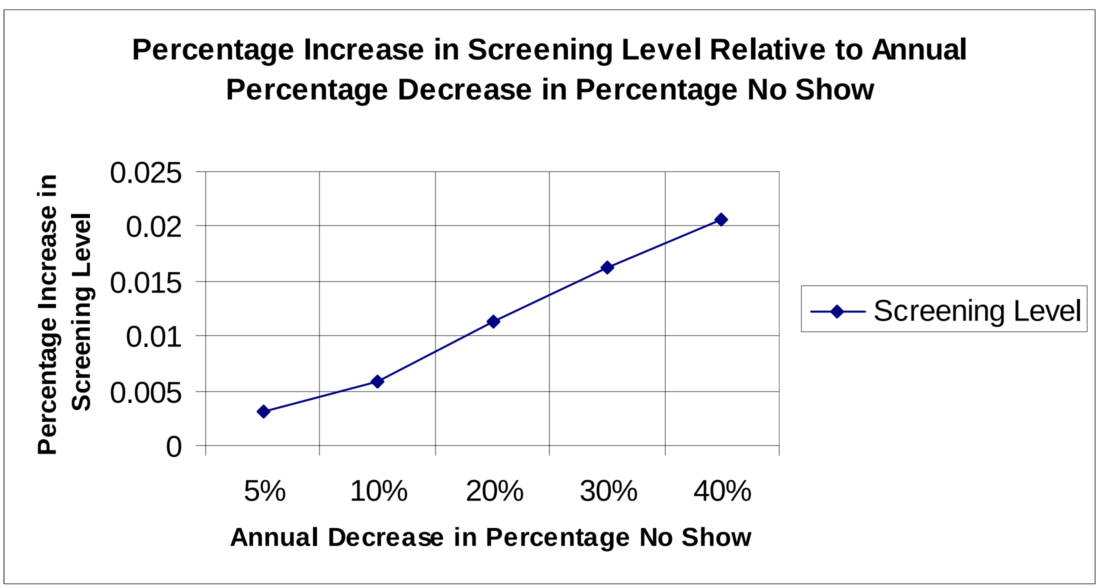

Figure 4.10: Percentage Increase in Screening Level Relative to Inclusion of Patient Reminder System

The following table (Table 4.20) gives the average percentage increase in the performance measures obtained when implementing the patient reminder system.

Table 4.20: Avg. Percentage Increase in Performance Measures for Inclusion of Patient Reminder System

SCENARIO	RESULTS		
Range for Annual Percentage Decrease in Percentage No Show	Average Percentage Increase in Awareness Level	Average Percentage Increase in Demand Level	Average Percentage Increase in Final Screening Level
5% - 40%	0	0	0.0114

Therefore, from Tables 4.18 and 4.20, it is apparent that on average the incorporation of the social support network, under the respective assumptions, would be more effective in increasing the screening level. This effect is reasonable because the inclusion of a social support network increases the demand for screening, whereas the inclusion of a patient reminder system just increases the number of people who have already demanded screening who actually get screened.

4.4.3 Physician Intervention Analysis

The following tables and figures give information pertaining to the percentage increase in the awareness level, demand level, and the screening level for the intervention schemes relative to improving the role of the physician.

Table 4.21: Percentage Increase in Performance Measures for Increase in PCP Awareness

SCENARIO	RESULTS		
Annual Percentage Increase in PCP Awareness	Percentage Increase in Awareness Level	Percentage Increase in Demand Level	Percentage Increase in Final Screening Level
5%	0.0238	0.0253	0.0022
8%	0.0385	0.0410	0.0038
10%	0.0485	0.0518	0.0046
12%	0.0586	0.0627	0.0055

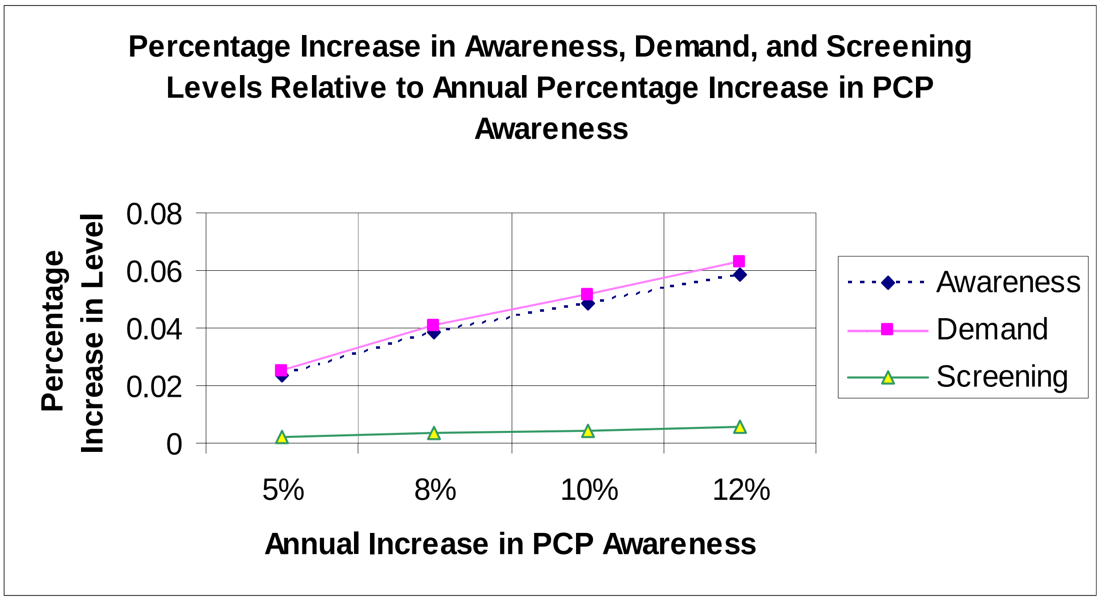

Figure 4.11: Percentage Increase in Performance Measures Relative to Increase in PCP Awareness

Table 4.22: Avg. Percentage Increase in Performance Measures for Increase in PCP Awareness

SCENARIO	RESULTS		
Range for Annual Percentage Increase in PCP Awareness	Average Percentage Increase in Awareness Level	Average Percentage Increase in Demand Level	Average Percentage Increase in Final Screening Level
5% - 12%	0.0423	0.0452	0.0040

Table 4.23: Percentage Increase in Performance Measures for Increase in PCP Compliance

SCENARIO	RESULTS		
Static Increase in Level of PCP Compliance	Percentage Increase in Awareness Level	Percentage Increase in Demand Level	Percentage Increase in Final Screening Level
0.10	0.1111	0.1111	0.0104
0.20	0.2222	0.2222	0.0209
0.30	0.3333	0.3333	0.0312
0.40	0.4444	0.4445	0.0411

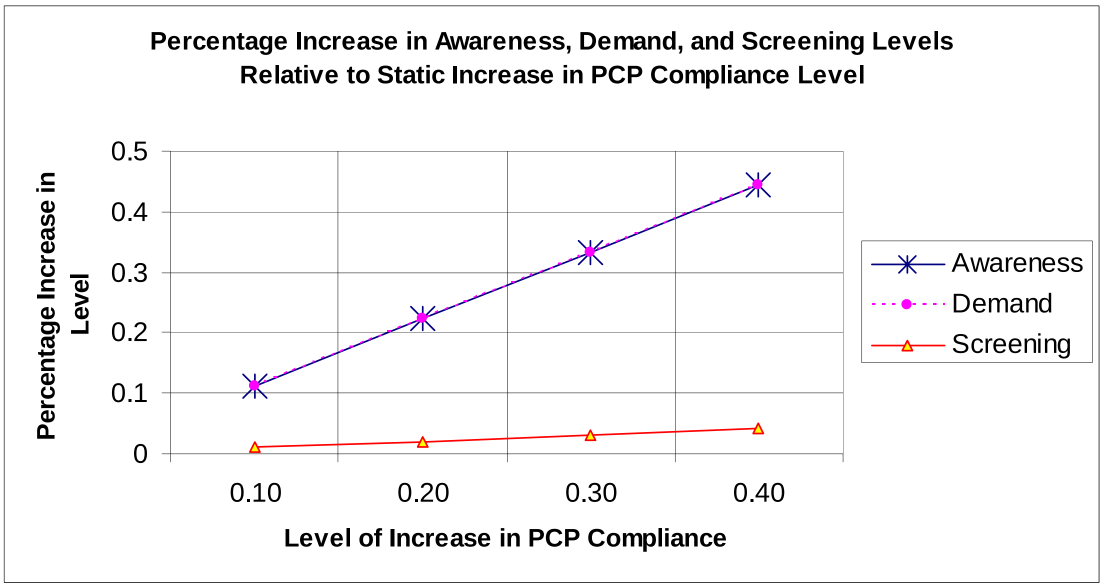

Figure 4.12: Percentage Increase in Performance Measures Relative to Increase in PCP Compliance

Table 4.24: Avg. Percentage Increase in Performance Measures for Increase in PCP Compliance

SCENARIO	RESULTS		
Range for Static Increase in Level of PCP Compliance	Average Percentage Increase in Awareness Level	Average Percentage Increase in Demand Level	Average Percentage Increase in Final Screening Level
.10 - .40	0.2778	0.2778	0.0259

In comparing Figure 4.12 to Figure 4.11, it is apparent that having a static increase in the level of PCP compliance is more effective than having an annual increase in PCP awareness. This result is logical given that compliance is ultimately, as discussed in previous sections, the critical factor in whether or not screening guidelines are followed and screening recommendations are given to the patients. In addition, notice how Figures 4.11 and 4.12 illustrate the percentage increase in the screening level relative to that for the awareness and demand levels. Both figures show a much lower percentage increase in the screening level compared to the percentage increase in the awareness and demand levels. Although this occurs, it is important to note that there are large differences in magnitude between the original screening level, and the awareness and demand levels in the base case scenario. Therefore, in this study a low percentage increase in the screening level does not imply a small increase in the number of people who get screened. Furthermore, from Tables 4.22 and 4.24, the intervention scheme regarding improvement in PCP compliance on average yields a higher screening level percentage increase than that regarding improvement in PCP awareness, 2.6% versus 0.4%, respectively.

Table 4.25: Percentage Increase in Performance Measures for Increase in PCP Awareness and PCP Compliance

SCENARIO		RESULTS		
Annual Percentage Increase in PCP Awareness	Static Increase in Level of PCP Compliance	Percentage Increase in Awareness Level	Percentage Increase in Demand Level	Percentage Increase Final Screening Level
5%	0.10	0.1349	0.1364	0.0127
5%	0.20	0.2460	0.2475	0.0231
5%	0.30	0.3571	0.3587	0.0335
5%	0.40	0.4682	0.4698	0.0439
8%	0.10	0.1496	0.1522	0.0141
8%	0.20	0.2607	0.2633	0.0244
8%	0.30	0.3718	0.3744	0.0349
8%	0.40	0.4829	0.4855	0.0454
10%	0.10	0.1596	0.1629	0.0152
10%	0.20	0.2707	0.2740	0.0254
10%	0.30	0.3818	0.3851	0.0358
10%	0.40	0.4929	0.4962	0.0463
12%	0.10	0.1697	0.1738	0.0159
12%	0.20	0.2808	0.2849	0.0266
12%	0.30	0.3919	0.3960	0.0367
12%	0.40	0.5031	0.5071	0.0472

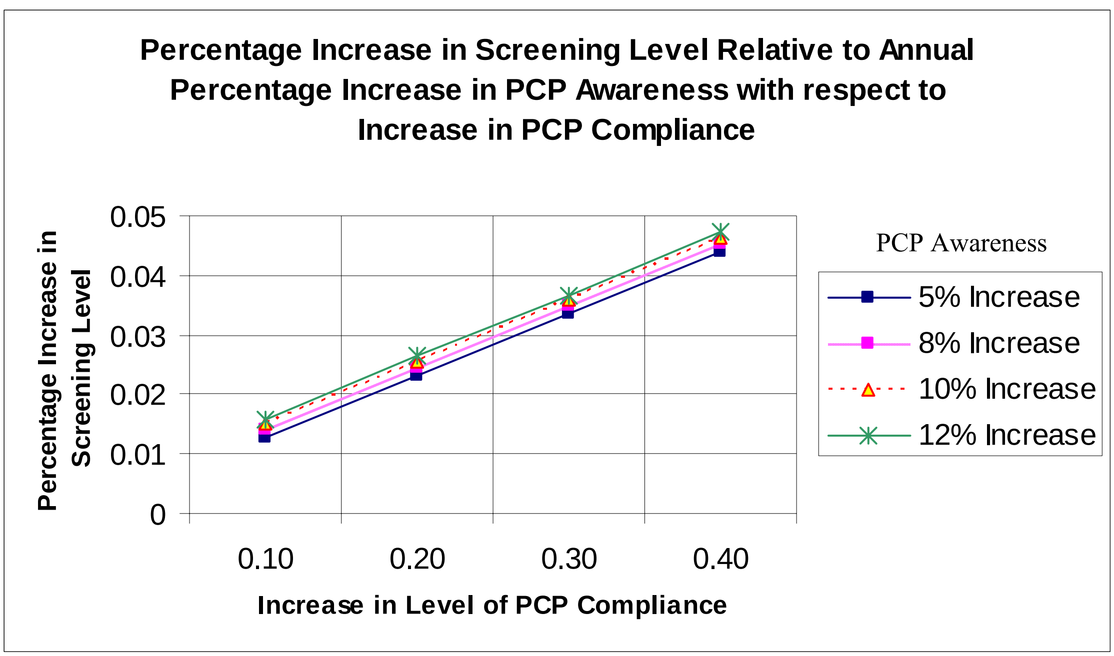

Figure 4.13: Percentage Increase in Screening Level Relative to Increase in PCP Awareness with respect to an Increase in PCP Compliance

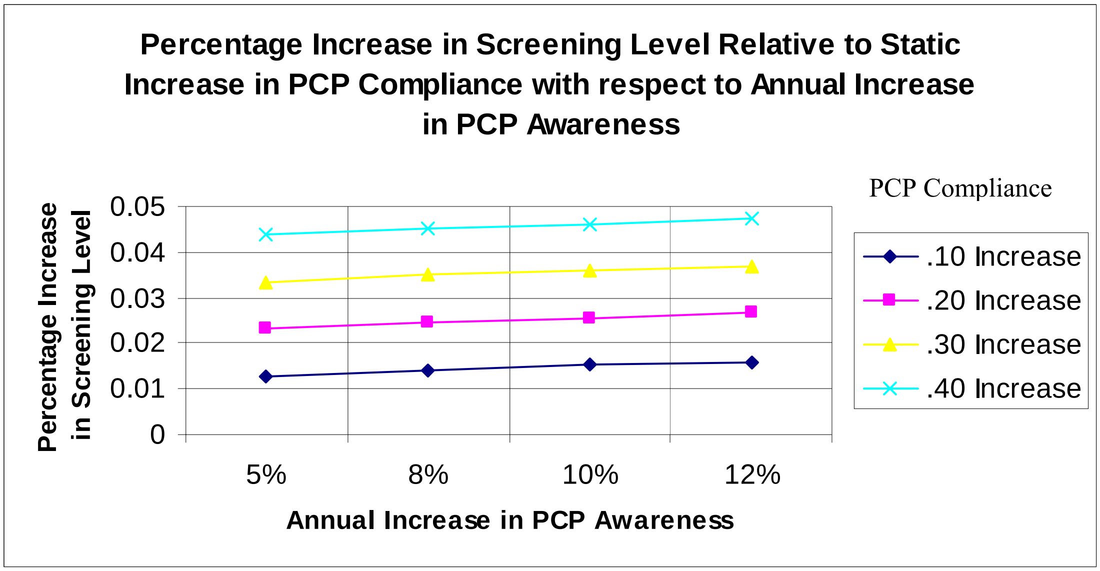

Figure 4.14: Percentage Increase in Screening Level Relative to Increase in PCP Compliance with respect to an Increase in PCP Awareness

Table 4.26: Avg. Percentage Increase in Performance Measures for Increase in PCP Awareness and PCP Compliance

SCENARIO		RESULTS		
Range for Annual Percentage Increase in PCP Awareness	Range for Static Increase in Level of PCP Compliance	Average Percentage Increase in Awareness Level	Average Percentage Increase in Demand Level	Average Percentage Increase Final Screening Level
5% - 12%	.10 - .40	0.3201	0.3230	0.0301

Figures 4.13 and 4.14 illustrate interesting and significant results. Essentially, these figures show how PCP compliance greatly impacts the CCC system. Notice that in Figure 4.14, there is minimal change (improvement) in the percentage increase in the screening level as the annual increase in PCP awareness improves. Thus, regardless of the level of increase in PCP compliance, the annual increase in PCP awareness has little effect. Actually, Figure 4.14 gives reason to infer that the level (height on graph) of the percentage increase in the screening level is influenced more by the level of PCP

compliance versus the level of PCP awareness. Figure 4.13, however, illustrates that the level of PCP compliance has just the opposite interaction effect with the level of PCP awareness. Figure 4.13 clearly shows a significant change (improvement) in the percentage increase in the screening level as the level of PCP compliance increases.

Table 4.27: Percentage Increase in Performance Measures for Improvement in Info. Exchange

SCENARIO	RESULTS		
Annual Percentage Improvement in Correctness of Information Exchange	Percentage Increase in Awareness Level	Percentage Increase in Demand Level	Percentage Increase in Final Screening Level
5%	0.0416	0.0443	0.0041
8%	0.0673	0.0718	0.0068
10%	0.0848	0.0906	0.0084
12%	0.1026	0.1096	0.0100

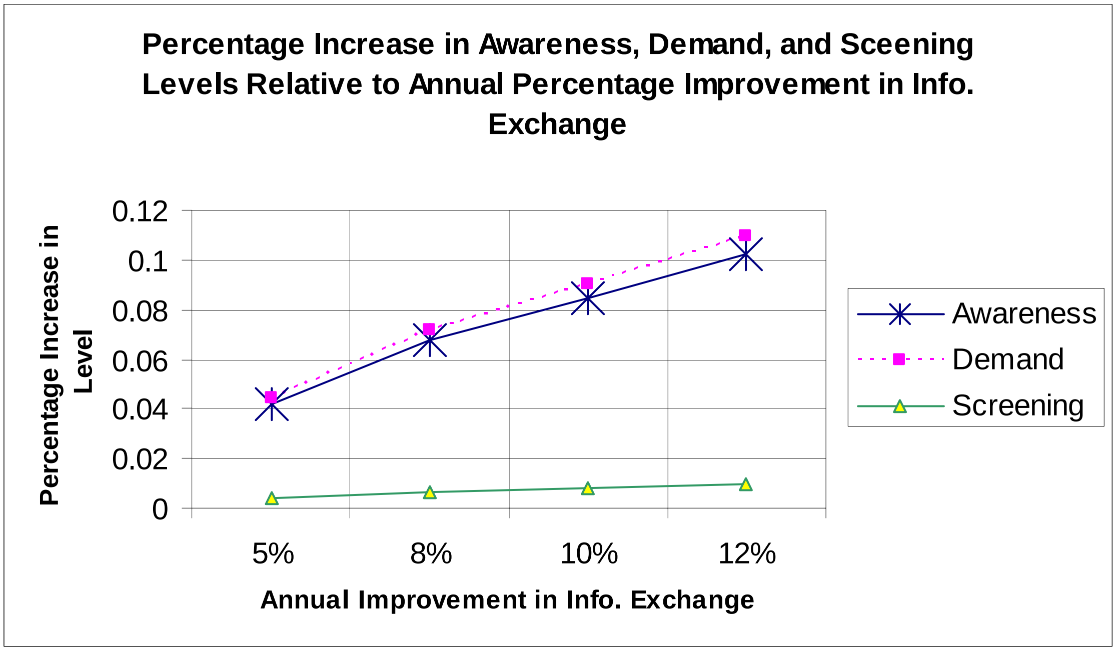

Figure 4.15: Percentage Increase in Performance Measures Relative to Improvement in Info. Exchange

Table 4.28: Avg. Percentage Increase in Performance Measures for Improvement in Info. Exchange

SCENARIO	RESULTS		
Range for Annual percentage Improvement in correctness of information exchange	Average Percentage Increase in Awareness Level	Average Percentage Increase in Demand Level	Average Percentage Increase in Final Screening Level
5% - 12%	0.0741	0.0791	0.0073

As can be seen above, the impact of improving the correctness of information exchange, and indirectly, the quality of physician-patient communication is examined. Figure 4.15 and Table 4.28 show that this intervention scheme does not result in a significant improvement in the screening level when compared to the intervention methods within this section, other than solely increasing PCP awareness (refer to Table 4.22). Moreover, from Tables 4.22, 4.24, 4.26, and 4.28, the most effective intervention scheme on average within this section is the combination of improving PCP awareness as well as PCP compliance.

4.4.4 Multimedia Intervention Analysis

This section reports the various values for the percentage increase in the performance measures resulting from the implementation of multimedia intervention, or simply large-scale public awareness.

Table 4.29: Percentage Increase in Performance Measures for Multimedia Intervention

SCENARIO	RESULTS		
Percentage Increase in Daily Awareness	Percentage Increase in Awareness Level	Percentage Increase in Demand Level	Percentage Increase in Final Screening Level
5%	0.0500	0.0608	0.0057
10%	0.1000	0.1217	0.0112
15%	0.1500	0.1825	0.0168
20%	0.2000	0.2433	0.0227
30%	0.3000	0.3650	0.0342
40%	0.4000	0.4867	0.0455
50%	0.5000	0.6083	0.0568

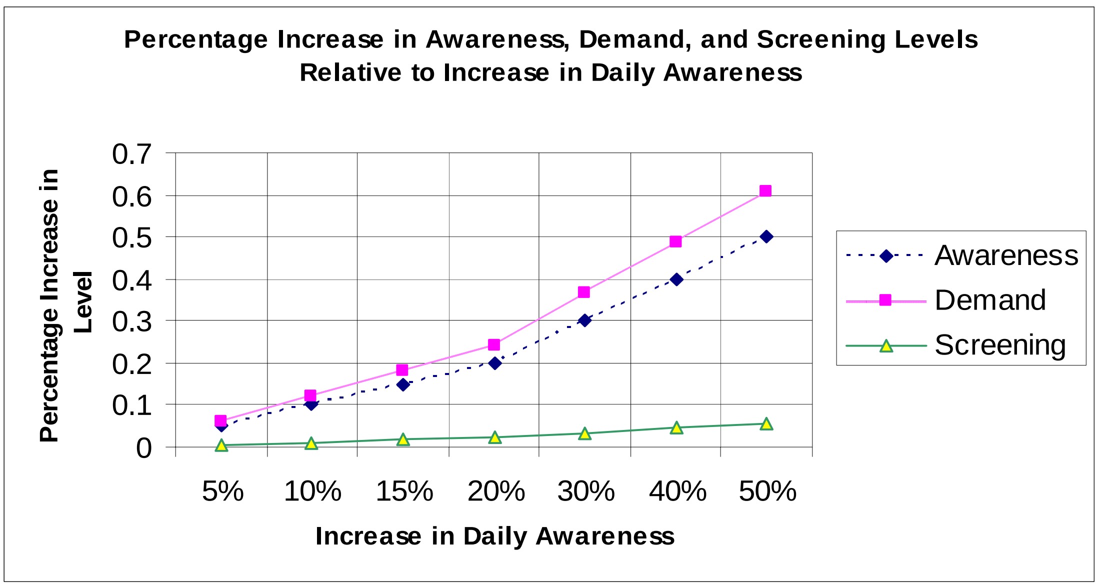

Figure 4.16: Percentage Increase in Performance Measures Relative to Improvement in Daily Awareness

Table 4.30: Avg. Percentage Increase in Performance Measures for Multimedia Intervention

SCENARIO	RESULTS		
Range for Percentage Increase in Daily Awareness	Average Percentage Increase in Awareness Level	Average Percentage Increase in Demand Level	Average Percentage Increase in Final Screening Level
5% - 50%	0.2429	0.2955	0.0276

Figure 4.16 shows how the screening level is affected from multimedia intervention when it impacts the daily awareness as given in Table 4.29. Relative to the previous intervention schemes analyzed, the impact of multimedia intervention on the screening level is pretty significant. Furthermore, Table 4.30 reports the averages in the percentage increase in the different performance measures, which are, again in comparison to previous results, significant.

4.4.5 Final Analysis

In the previous sections (4.4.1 – 4.4.4), we examined the behavioral impact of each individual intervention scheme on the different performance measures, but most importantly, the most significant of them all, the screening level. But, what would be the effect of a combination of all of the intervention schemes? This is an important question and it will be answered in this section to some extent. This section will report the results for three scenarios, each at two different levels, yielding a total of six different scenarios. Two of the scenarios involve including the increase in rural PCP accessibility, one with 10% and the other at 100%. These values have been chosen in an effort to create a range for the improvement in the screening level, which can be understood more as this section progresses. The third scenario involves including the increase in rural PCP accessibility, but at 50%. This increase was done in order to get a midpoint in the range for the improvement in the screening level, particularly as it relates to an increase in rural PCP capacity. Furthermore, the two levels are referred to as *high* and *low*. The *high* and *low levels* are representative of having all the intervention schemes, outside of those corresponding to resource capacity, at their highest levels and lowest levels, respectively.

Please refer to the various tables throughout sections 4.4.1 through 4.4.4 for these different values. In addition, it is important to note that all of these scenarios also include an increase in screening facilities, and is the same as what is referred to in Table 4.15. The results from the six scenarios are reported below. The results were obtained after running 20 replications.

Table 4.31: Results for Intervention Combination

** All Results ≥ 1 have been rounded up to the nearest integer**

SCENARIO				RESULTS					
PCP Interarrival Time (in days) Distribution	Number of PCPs per Arrival	Percentage of New PCPs designated for NC Rural Area	Intervention Combination Level	Average Awareness Level	Average Demand Level	Average Screening Level at Time 365	Average Screening Level at Time 730	Average Final Screening Level	Average Final Screening Rate
Expo(60,3)	30	10%	*High*	1471739	382957	846284	920887	1001189	0.4394
Expo(60,3)	30	50%	*High*	1944174	526275	865110	979829	1119977	0.4915
Expo(60,3)	30	100%	*High*	2907928	828538	884697	1072354	1326400	0.5821
Expo(60,3)	30	10%	*Low*	732798	147316	733640	757986	779529	0.3421
Expo(60,3)	30	50%	*Low*	960090	199888	741677	777801	815981	0.3581
Expo(60,3)	30	100%	*Low*	1419103	308967	753337	811244	887499	0.3895

Table 4.32: Percentage Increase in Performance Measures relative to Intervention Combinations

SCENARIO				RESULTS		
PCP Interarrival Time (in days) Distribution	Number of PCPs per Arrival	Percentage of New PCPs designated for NC Rural Area	Intervention Combination Level	Percentage Increase in Awareness Level	Percentage Increase in Demand Level	Percentage Increase in Final Screening Level
Expo(60,3)	30	10%	*High*	1.6558	2.8394	0.3472
Expo(60,3)	30	50%	*High*	2.5083	4.2763	0.5070
Expo(60,3)	30	100%	*High*	4.2474	7.3067	0.7848
Expo(60,3)	30	10%	*Low*	0.3224	0.4770	0.0489
Expo(60,3)	30	50%	*Low*	0.7325	1.0040	0.0980
Expo(60,3)	30	100%	*Low*	1.5608	2.0976	0.1942

Tables 4.31 and 4.32 illustrate the wide range for improvement in the screening level respective to the different intervention combinations. In particular, a *low* intervention combination level with the smallest increase in NC rural PCPs yields an average screening level of 779529, and a screening rate of 0.3421, while a *high* intervention combination level with the largest increase in NC rural PCPs yields an average screening level of 1326400, and a screening rate of 0.5821. Notice that both of these scenarios yield a higher screening rate than that for the base case scenario. In fact, all of the scenarios within the intervention combination category are more effective than the base case scenario because on average they produce higher screening rates than 32.61%. In addition, in comparison to the results reported by the ACS (screening rate equal to ~35.1% in the beginning of 2003), the combination of intervention schemes are reasonably effective. Although some of the intervention schemes are somewhat drastic, as in the case of having 100% of new PCPs designated to rural NC, the results in tables 4.31 and 4.32 give a sense as to how much potential there is for attaining amazingly high screening levels through the implementation of interventions.

5 CONCLUSIONS and FINAL REMARKS

Although colon cancer is a serious threat to the US society, there are preventative measures, such as screening, that can be taken to either hinder the development of colon cancer, or detect it before it metastasizes. However, despite the effectiveness of screening, there is a very low percentage of the US population that takes advantage of screening.

Barriers to colon cancer care (CCC) serve as the main reason for the lack of screening. In this thesis, several of these barriers are discussed and intervention schemes are proposed to help alleviate some of these barriers. Through simulation modeling these barriers and their effectiveness with regards to the improvement in the screening level are examined.

Overall, this study focuses on four main categories of intervention schemes. They include an improvement in resource capacity, patient adherence intervention, physician intervention, and multimedia intervention. In general, most of the intervention schemes prove to be effective on average in comparison to the base case scenario. More specifically, in this study the three most effective individual intervention schemes are the following: increasing the number of rural PCPs, improving the role of the physician in his/her awareness and compliance, and instituting multi-media intervention (refer to Table 4.26 and Table 4.30). It is important to note that on average, the increase in the percentage of rural PCPs is the most effective. This result not only strongly supports the significance and impact of the rural community on a population, but the true existence of disparity and its magnitude within the rural population with respect to health care. Furthermore, a similarity among the top three intervention methods is that each has a significant and direct effect on the awareness of the population. Therefore, it is reasonable for them to have the greatest effects because awareness is key, and is the fundamental influential factor in the CCC system; for from awareness follows the possibility for demand, which is then followed by the possibility of getting screened.

Moreover, in this study, the power in combining intervention schemes is discovered. A range for improvement in the screening level is created by obtaining the results for an intervention combination, where its factor variables are at their lowest level of influence, and for an intervention combination, where its factor variables are at their highest level of influence. Although some of the extreme cases might be viewed as unrealistic, the percentage increase in the screening level ranged from 4.9% to 78.5%. Furthermore, these results show that achieving a screening rate of 35.1% or higher is possible from this approach, which illustrates its effectiveness.

Furthermore, this simulation study recognizes the importance and positive influence in executing interventions. It also gives an idea of the expected behavior of the CCC system. While this is appropriate and helpful in analyzing the CCC system, further research can be performed to determine what other means of intervention can be executed to improve colon cancer screening. For instance, one suggestion is to examine the effect of a public transportation system in helping people get to the screening facilities. Another suggestion may be to investigate more intricate economic factors, such as having an increase in insurance coverage and lower out-of-pocket costs. Also, this study looked into increasing the number of screening facilities; but, there is also the possibility of increasing the number of screening practitioners and the number of daily procedures within each facility. In addition, it may be interesting to focus in on one population characterized by certain demographics, and investigate intervention mechanisms geared towards that particular population. Furthermore, in examining the various approaches to intervention, cost analysis could also be performed. Cost analysis is important because although an intervention scheme may be highly effective, it could also be very costly. Cost analysis will allow one to examine the trade-offs in the improvement in screening versus the associated costs. Overall, this study provides the "ground work" for analyzing the CCC system with respect to screening, and future research can provide the means to get a more accurate depiction of the dynamics of the CCC system, and a more extensive view of the effect in intervention.

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