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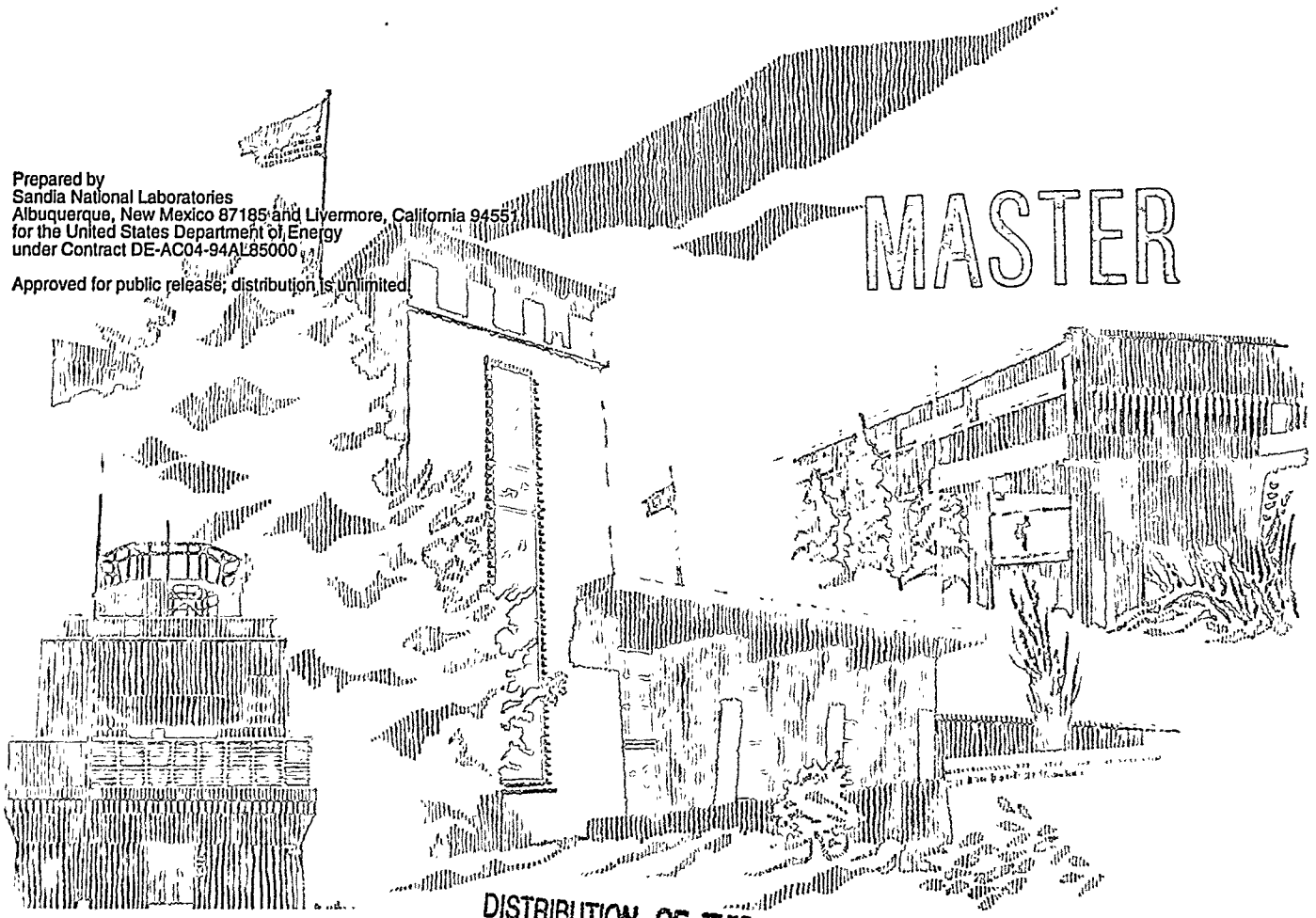
Kaiser Permanente - Sandia National Health Care Model

Phase I Prototype Final Report
Part 1 - Model Overview

David Butler, David Eddy, Donna Edwards, Richard Judson, Robert Mariano, William Mason, Leonard Napolitano, Leonard Schlessinger, Ann Yoshimura



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KAISER PERMANENTE / SANDIA NATIONAL HEALTH CARE MODEL
Phase I Prototype Final Report
Part 1 - Model Overview

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ABSTRACT

This report describes the results of a Cooperative Research and Development Agreement (No. 01179W) between Sandia National Laboratories and Kaiser Permanente Southern California to develop a prototype computer model of Kaiser Permanente's health care delivery system. As a discrete event simulation, SimHCO models for each of 100,000 patients the progression of disease, individual resource usage, and patient choices in a competitive environment. SimHCO is implemented in the object-oriented programming language C++, stressing reusable knowledge and reusable software components. The versioned implementation of SimHCO showed that the object-oriented framework allows the program to grow in complexity in an incremental way. Furthermore, timing calculations showed that SimHCO runs in a reasonable time on typical workstations, and that a second phase model will scale proportionally and run within the system constraints of contemporary computer technology.

This report is published as two documents: Model Overview and Domain Analysis. A separate Kaiser-proprietary report contains the Disease and Health Care Organization Selection Models.

EXECUTIVE SUMMARY

Background

This report describes the results of a Cooperative Research and Development Agreement between Sandia National Laboratories and Kaiser Permanente Southern California to develop a prototype computer model of Kaiser Permanente's health care delivery system. Like all other health care providers, Kaiser Permanente must efficiently allocate expensive and often scarce resources. The job is especially difficult because a large health care system is a complicated combination of interconnected and interacting pieces. The operation of an HMO such as Kaiser Permanente is driven by a large number of decisions affecting health care delivery (What is the most appropriate treatment for a given set of symptoms?); capital outlay (What are the economics of building a new hospital in an emerging suburb?); economic competitiveness (What rate structure will best balance the number of members and the treatment they receive?); and many other issues. Additionally, given limited financial resources, decision makers are increasingly having to make tradeoffs between economic and patient treatment outcomes. There exists an urgent need for tools to help guide the decision making process in all of these areas.

In 1993, Kaiser Permanente and Sandia formed a team to determine the feasibility of and begin the development of the Kaiser Permanente-Sandia National Health Care Model (herein after called the Kaiser-Sandia model), a large-scale computer-based simulator of a modern health care system. The simulator will capture the interactions between important pieces of the health care system and characterize the details of each piece. The long range plan for the Kaiser-Sandia model envisions it containing many submodels of both disease and operations types. The overall simulator will link many submodels, along with financial models, to form an integrated and comprehensive picture of the entire system. That is, the Kaiser-Sandia model will include the all-important connections and interactions between different diseases, and between diseases, operations and finances. This property of the model will give it considerably greater power to optimize delivery of care over a broad range of alternatives. The inclusion of many submodels, along with their interactions will make the Kaiser-Sandia model a much more powerful tool for decision makers than any currently existing, single domain model.

Purpose

Because the model outlined above will stress the limits of current simulation technology, we decided to proceed in two phases. The first phase would answer important feasibility questions before the second phase would proceed with the larger effort. The first phase has now been completed, and is described in this report.

The purpose of Phase I was to develop a prototype computer-based model (which we call SimHCO) that both could explore the feasibility of the full model and would be large enough to be credible, interesting, and useful as a learning tool. The technical objectives of Phase I were the following:

1. Can we define the domain (facilities, members, diseases, policies)?
2. Can we build sufficiently detailed interacting disease models?
3. Can we pose policy questions in the framework of the models?
4. What are the issues of extendibility and performance of the model?

The feasibility prototype is not a miniature version of the Phase II product. The Phase I prototype model contains specific hard-coded examples of the important components of the larger model, but does not contain all of the general formulations necessary for the larger model.

Method

Our methodology included the following five steps:

1. Determine the general system elements and the structure of the model.
2. Build examples of each system element.
3. Implement the model.
4. Pose policy questions.
5. Investigate the extendibility and performance of the model.

Results

We performed a domain analysis to determine the general elements of the system (facilities, members, diseases, and policies) and the overall structure of the model. We determined that a patient-based, stochastic, event-driven simulation model designed in an object-oriented framework would provide the necessary structure, functionality, and extendibility to meet the needs of the larger model. SimHCO includes a population database that represents the entire population of some geographical area (Southern California), one or more health care organizations (including detailed representations of their facilities) that serve the population, the management and medical practice policies database that represents one or more scenarios of provider care, and the disease / intervention and business practice models that describe the interactions of the members of the population with the health care organizations, and the event queue that drives the simulation.

Within that framework, we designed examples of each system element: multiple health care facilities, three detailed diseases (coronary artery disease, perinatal care, and human

immunodeficiency virus / acquired immune deficiency syndrome), several reduced detail (ICD-9) diseases, and one management problem (rate setting in the context of the selection model for how people select their health care organization).

The health care facilities (Hospitals, Departments, Rooms) are specified as a general structure so that a modeler can create any facilities configuration by simply defining hierarchically the number of health care organizations (HCOs), for each HCO the number of departments, and for each department the number and characteristics of rooms. As a simple example, one configuration would be one HCO (Kaiser) with three departments (Primary Care, Cardiology, and Obstetrics / Gynecology). Each of these departments has one waiting room. Primary care and Ob/Gyn have five examining rooms each. Cardiology has three examining rooms. Primary care examining room #1 has a thermometer, blood pressure monitor, scale, etc.

The disease models are designed according to a common general form and at a level of detail necessary to determine the effects of different diagnosis and treatment policies. We model the incidence and progression of diseases in each individual person according to that person's genetics, risk factors, medical history, behaviors, and medical treatments. For each disease in each person, we track the time evolution of one key disease feature. The status of that key feature determines the status of other disease features, as well as the signs and symptoms and health outcomes for the disease. For example, a person's risk of coronary artery disease depends on gender, family history of heart trouble, previous treatments for hypertension, smoking behavior, and the administration of beta-blockers. We model the occlusion of the patient's coronary arteries as dependent on these factors. The level of occlusion determines the probability of chest pain, angina, myocardial infarction, and sudden death. These medical events determine when and how a person interacts with the health care facilities.

The ICD-9 disease models simulate the load on the health care facilities of patients receiving treatment for all other diseases not modeled at the higher level of detail. People have other diseases according to national statistics on the probabilities of those diseases. On average, then, each patient contacts the health care facilities three times per year.

The HCO Selection Model is a model of people's behavior as it pertains to the choice of HCO. Each person has certain behavior characteristics, and certain ideas about the importance of various factors such as costs, service, health outcomes, and an overall perceived "brand value" of the HCO. These behaviors and beliefs coupled with people's experience with an HCO contribute to their decisions about membership renewal each period. The HCO Selection Model we used was a proprietary model provided by Kaiser Permanente.

We implemented the model and a graphical user interface on a standard workstation platform. We tested scenarios such as one HCO under different cholesterol screening policies and two HCOs competing for members. We observed over a given time horizon model outputs such as the market share of the HCOs, the amount of money collected and spent by the HCOs, the number of myocardial infarctions, births, and cases of HIV infection in the population. We also examined the medical history and health care spending of individual patients.

We investigated the extendibility of the model. We found that the general structure of the model and the object-oriented design allow for great flexibility in the HCO facilities configuration and for straight-forward addition of disease models. The facilities and disease models were implemented in an incremental approach, one disease at a time. The design of the code allowed the reuse of knowledge and software and minimized the need to redesign or recode previously implemented elements.

We investigated the performance of the model. We found that SimHCO required 383.6 CPU seconds to run three complex diseases in a population of 20,000 people for a period of 10 years. We performed scaling calculations to determine the CPU time required for a one year simulation run of the larger model with 80 diseases and 2,000,000 people. Our calculations estimate the CPU time to be 55.2 hours on a 200 MHz Pentium Pro (P6) machine running LINUX. Based on extrapolating past performance gains, we can predict that the fastest workstations in 5 years will be 18-25 times faster than the P6, so the target simulation will be able to be run in 2.2 to 3.1 CPU-hours per year of simulated time. This leads to 44.1 to 61.3 CPU-hours for a 20 year simulation. We anticipate that it will be possible to take advantage of shared memory multiprocessor machines, with a relatively small number of processors (~32) without large changes in the underlying discrete event methodology. This would reduce the wall clock time to about between 1.4 and 1.9 hours for a 20 year simulation. Thus, we predict that the Phase II model will run within the system constraints of contemporary computer technology.

Conclusion

Phase I accomplished its purpose and objectives. SimHCO is a working prototype computer model that contains a few examples of each important system element: multiple health care facilities, three detailed diseases (coronary artery disease, perinatal care, and human immunodeficiency virus / acquired immune deficiency syndrome), several reduced detail (ICD-9) diseases, and one management problem (rate setting in the context of the HCO Selection Model for how people select their HCO). The project team selected the components of the prototype through the domain analysis of the system, and determined that the detailed models combined by a high-level structure would address interesting and important clinical and managerial questions. The team developed and parameterized complex, interacting, statistically accurate disease models, and described the health care facilities and personnel required in the treatment of these diseases. The team designed the model as a discrete-event simulation that explicitly tracks the time progression of the physiological attributes (weight, height, arterial occlusion, CD4 cell count, etc.) of each patient, the prescription of treatments and outcomes of diseases in each patient, the resource usage by each patient, and patient choices in a competitive environment, for populations of up to 100,000 members. The team implemented SimHCO in the object-oriented programming language C++, stressing reusable knowledge and reusable software components. The versioned implementation of SimHCO showed that the object-oriented framework allows the program to grow in complexity in an incremental way without having to reprogram existing features. Furthermore, timing runs showed that SimHCO runs in a reasonable time on typical workstations, and that the Phase II model will scale proportionally and run within the system constraints of contemporary computer technology.

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INTRODUCTION

This report describes the results of a Cooperative Research and Development Agreement between Sandia National Laboratories and Kaiser Permanente Southern California to develop a prototype computer model of Kaiser's health care delivery system. Like all other health care providers, Kaiser must efficiently allocate expensive and often scarce resources. The job is especially difficult because a large health care system is a complicated combination of interconnected and interacting pieces. The operation of an HMO such as Kaiser is driven by a large number of decisions affecting health care delivery (What is the most appropriate treatment for a given set of symptoms?); capital outlay (What are the economics of building a new hospital in an emerging suburb?); economic competitiveness (What rate structure will best balance the number of members and the treatment they receive?); and many other issues. Additionally, given limited financial resources, decision makers are increasingly having to make tradeoffs between economic and patient treatment outcomes. There exists an urgent need for tools to help guide the decision making process in all of these areas.

Over the last several years, a number of simple computer models have been developed to address a limited domain of this large problem. There already exist operations-research type models that simulate various processes such as the scheduling of operating rooms or staffing labor and delivery suites. There also exist models that describe the progression of a particular disease and the effects of different disease management strategies. These models can be quite detailed and useful, but they are designed to optimize only one operation or procedure at a time.

An appealing extension of these approaches would be the development of a large computer simulation that combines models of many individual pieces of the health care system, as well as their interactions. With such a simulation, decision makers could begin to play "what if" games and understand important and non-obvious system-wide consequence of proposed actions. A system-wide model would allow health care providers and administrators to "see" what is happening now and predict how medical interventions and administrative decisions will reverberate through the system and into the future. Executives would be able to "try" different administrative policies (in such areas as marketing, staffing, and capital expenditures), quantify short term and long term effects, and choose the most effective and efficient policies. Similarly, clinicians would be able to "try" different disease interventions, quantify short term and long term effects, and choose the most effective and efficient course of treatment. Executives and clinicians together would be able to evaluate the financial impact of their clinical decisions and the clinical impact of their financial decisions.

The ideal simulator would be able to predict many types of events and the complex interactions between events. For example, a simulation could forecast, five years in the future, the effect of a diet education program on such varied factors as the use of education conference rooms, the distribution of serum cholesterol levels in the health plan's population, the occurrence of coronary artery events, the number of angioplasties, the need to recruit cardiologists, the budget for sterile gloves, and the need for overflow parking. This type of simulator should be useful for a wide range of purposes such as designing practice guidelines, forecasting demand, predicting utilization and resource needs, planning facilities personnel and operations, optimizing resource use, setting priorities and setting rates.

In 1993, Kaiser and Sandia formed a team to determine the feasibility of and begin the development of the Kaiser-Sandia National Health Care Model (herein after called the Kaiser-Sandia model), a large-scale computer-based simulator of a modern health care system. The simulator will capture the interactions between important pieces of the health care system and characterize the details of each piece. The long range plan for the Kaiser-Sandia model envisions it containing many submodels of both disease and operations types. The overall simulator will link many submodels, along with financial models, to form an integrated and comprehensive picture of the entire system. That is, the Kaiser-Sandia model will include the all-important connections and interactions between different diseases, and between diseases, operations and finances. This property of the model will give it considerably greater power to optimize delivery of care over a broad range of alternatives. The inclusion of many submodels, along with their interactions will make the Kaiser-Sandia model a much more powerful tool for decision makers than any of the currently existing, single domain models.

Phase I Overview

Because the model outlined above will stress the limits of current simulation technology, we decided to proceed in two phases. The first phase would answer important feasibility questions before the second phase would proceed with the larger effort. The first phase has now been completed, and is described in this report.

The purpose of Phase I was to develop a prototype computer-based model (which we call SimHCO) that both could explore the feasibility of the full model and would be large enough to be credible, interesting, and useful as a learning tool. The initial technical objectives of Phase I were the following:

1. Determine and define the domains to be modeled,
2. Build an implementable natural language-based information model of the defined domains,
3. Create a software design specification, and
4. Test and demonstrate the system to meet requirements of extendibility and implementation.

During the course of Phase I, as the combined Sandia and Kaiser Permanente team gained experience and expertise with the project, the initial abstract objectives evolved into the following set of concrete questions:

1. Can we define the domain (facilities, members, diseases, policies)?
2. Can we build sufficiently detailed interacting disease models?
3. Can we pose policy questions in the framework of the models?
4. What are the issues of extendibility and performance of the model?

Phase I accomplished its purpose and objectives. SimHCO is a working prototype computer model that contains a few examples of each important system element: multiple health care facilities, three detailed diseases (coronary artery disease, perinatal care, and human immunodeficiency virus / acquired immune deficiency syndrome), several reduced detail (ICD-9) diseases, and one management problem (rate setting in the context of the HCO Selection Model for how people select their HCO). The project team selected the components of the prototype through the domain analysis of the system, and determined that the detailed models combined by a high-level structure would address interesting and important clinical and managerial questions. The team developed and parameterized complex, interacting, statistically accurate disease models, and described the health care facilities and personnel required in the treatment of these diseases. The team designed the model as a discrete-event simulation that explicitly tracks the time progression of the physiological attributes (weight, height, arterial occlusion, CD4 cell count, etc.) of each patient, the prescription of treatments and outcomes of diseases in each patient, the resource usage by each patient, and patient choices in a competitive environment, for populations of up to 100,00 members. The team implemented SimHCO in the object-oriented programming language C++, stressing reusable knowledge and reusable software components. The versioned implementation of SimHCO showed that the object-oriented framework allows the program to grow in complexity in an incremental way without having to reprogram existing features. Furthermore, timing runs showed that SimHCO runs in a reasonable time on typical workstations, and that the Phase II model will scale proportionally and run within the system constraints of modern computer technology.

Deliverables

The project deliverables, as outlined in the CRADA Statement of Work, are the domain analysis and four incremental versions of SimHCO. The final version of SimHCO includes the capabilities of all earlier versions, and its components are described here.

1. Domain Analysis - The domain analysis determined the questions the simulator should answer and the appropriate level of detail. The result was a structure for SimHCO that allowed each of the required models to be implemented.
2. Three Diseases, with Diagnoses and Treatments - SimHCO contains working models of coronary artery disease (CAD), perinatal care, and human immunodeficiency virus /

acquired immune deficiency syndrome (HIV/AIDS). Each of these models contains detailed descriptions of the relevant physiological and behavioral processes within a patient, as well as diagnosis and treatment models used by health care providers. Additionally, all other possible diseases are represented at a very high level as broad ICD-9 categories.

3. Membership Behavior Model/Rate Setting - SimHCO includes a model of member behavior for choosing which of several HCOs to join. The behavior depends (among other variables) on the rates charged by different HCOs.

4. Facilities - SimHCO contains all of the facilities (Hospitals, Departments, Rooms) required for the diagnosis and treatment of the three diseases and for multiple HCOs competing for members. The facilities are implemented as a general structure so that a modeler can create any facilities configuration by simply defining hierarchically the number of HCOs, for each HCO the number of departments, and for each department the number and characteristics of rooms.

5. Policies - SimHCO includes policies that describe disease diagnosis and treatment and HCO rate setting.

6. Policy Editor - SimHCO demonstrates the feasibility of a visual programming interface that allows policies to be edited in real time. The selection policy for cholesterol screening is represented as a user-modifiable flow chart, and the logic in the flow chart is converted into executable computer code at the end of an editing session.

7. Graphical User Interface - The GUI allows most simulation variables to be queried and many to be set interactively.

The original statement of work envisioned three additional deliverables. The project team considered each of these during the course of the prototype design and decided not to pursue them in Phase I.

1. Graphical Animation - The project team judged this feature to be a nice enhancement, but not necessary or feasible given the time constraints of the Phase I project.

2. NIAM Process Description - The project team members attended a week-long NIAM training session and concluded that the level of detail was excessive for SimHCO.

3. Second Business Practice - Kaiser team members decided to postpone additional business practice models until the Phase II project.

Outline of the Report

This report is published as two documents: Model Overview and Domain Analysis. A separate Kaiser-proprietary report contains the Disease and Health Care Organization Selection Models.

Part 1 of the report, Model Overview, is organized around the objective questions. The section "Domain Definition" provides a high-level description of SimHCO, including the population, the disease and behavior models, the health care organizations, and the management and clinical policies. The section "Disease Models" provides a general description of each of the disease models. The section "Behavior Model for Choice of HCO" provides a general description of the HCO Selection Model. The section "Policy Questions" shows how the complete model can be used to address different policy questions. The section "Model Extension" describes how the object-oriented design methodology allows for straight-forward extensions of SimHCO. The section "Model Computational Performance" shows timing information for SimHCO. The appendix contains a Brief User's Guide.

Part 2 of the report, Domain Analysis (which is published as a separate report), contains a description of the High-Level Structure of the Model.

A separate Kaiser-proprietary report, Disease and HCO Selection Models, contains a Detailed Description of the Coronary Artery Disease Model, Model Validation and Verification for the Coronary Artery Disease Model, and Detailed Descriptions of the Perinatal Care Model, the Human Immunodeficiency Virus Model, and the HCO Selection Model.

DOMAIN DEFINITION

We defined the domain of the problem (and the structure of SimHCO) to include four major components:

- the entire population of a geographical area (Southern California),
- the behavior and disease models that for each person determine stochastically the choice of HCO membership and the incidence and progression of diseases,
- one or more health care organizations that serve the population of the region,
- and the management and medical practice policies that represent one or more scenarios of provider care.

SimHCO models the interaction of these components over a period of time as people age, change their behaviors, acquire diseases, have diseases that progress in time, seek and receive medical care, join and leave health plans, pay premiums to the health plan, and pay co-payments at hospital and health clinic visits. The next sections describe each of the components of SimHCO and the event queue, which controls and organizes the interactions of these components.

Population

The population database in SimHCO represents the members of the population of a geographical area (Southern California) at one snapshot in time. The database holds individual information about every (hypothetical) person in the simulation, including each person's identification, gender, birth date, medical care bank account balance, behavior characteristics, genetic information, risk factors for diseases, current status of diseases, and medical history. During a simulation run, each of these pieces of information is chosen or updated stochastically according to national statistics or specified disease / intervention or behavior models.

Prior to and separate from the simulation runs, the initial population database must be specified with appropriate values of internal parameters and medical histories. In theory, one could obtain some of the database information from a real medical records database and infer the values of the unobservable parameters from the observed parameters. For SimHCO, we had available minimal demographic information and no medical record information. Thus, we generated a population database by using the available demographics and running SimHCO to set and update the peoples' internal parameters and medical histories.

The population generator creates each person in three steps: initialization, simulation, and output. The population generator initializes each person by setting that person's gender, type of membership (individual, couple, or family), and birth date (which can be as far back as 100 years before the desired start time for the simulation runs). Each of these parameters is set statistically, so that the resulting database at the start time matches the Kaiser demographics for gender, type

of membership, and age. To fill out the peoples' internal parameters and medical histories, the population generator uses SimHCO. For each person, the generator runs SimHCO starting 100 years before the desired start time for the simulation runs. During the hundred year simulation run, the person is born on his/her birth date; has diseases that occur, progress, and cause symptoms and events; and seeks care and receives treatment for diseases. It is possible that a person dies before the end of the hundred year simulation run. In that case, the generator creates a new person. If the person is a member of a couple or a family, the generator repeats the process to create the additional people in that membership group. After the generator has created a membership group, the generator writes out those people to the database. Each person plus his/her membership status and grouping, internal parameters and medical histories is recorded in the database.

Disease and Behavior Models

The behavior and disease models describe for each person the choice of HCO membership and probabilistic occurrence and progression of diseases according to the person's risk factors, genetics, behaviors, and interventions. Thus the behavior and disease models determine people's interactions with the HCOs and their health events. These models are discussed in a general overview in a later section, and in more detail in the appendices.

Health Care Organization

The population may be served by one or more health care organizations (HCOs). Depending on the current policy question, an analyst may be interested in simulating different HCO scenarios. SimHCO has the flexibility to accommodate any number of HCOs serving the population, and each of those HCOs may have different facilities configurations and different management and clinical policies. For Phase I, we have built in four particular configurations: Kaiser (a simulation of a Kaiser Permanente HCO), Kaiser vs Kaiser (a simulation of two Kaiser Permanente HCOs that are identical except for policy differences), Two HCOs (a simulation of a Kaiser Permanente HCO competing for members against another HCO), and Four HCOs (a simulation of a Kaiser Permanente HCO competing for members against three HCOs, nominally called Pacific Care, Blue Cross, and Foundation Health Plan). In all of these configurations, the general structure of the HCOs is the same, such that each HCO has the following four parts: a health plan (its members), its hospital / medical center facilities, its management and clinical policies, and a medical group (its doctors). The next sections describe the parts of the HCO in more detail.

Health Plan

Each HCO has a health plan that consists of two parts: its members and its accounting system. The health plan members are a subset of the entire population of the geographical area, and thus are simply represented by an identifier field for each person in the population database.

The health plan accounting system receives premium and premium-sharing payments from the members, and pays the hospitals/medical centers and the physician group for their services.

Hospital / Medical Center Facilities

The hospital / medical center facilities of each HCO are represented in a database that contains the hierarchical description. Each HCO may have any number of medical centers (for outpatient care) and hospitals (for inpatient care). Each medical center has appointment facilities and medical departments. Each hospital has admitting / discharge facilities, medical departments, and emergency rooms. The types of medical departments in SimHCO are family practice, cardiology, and obstetrics / gynecology. Each medical department in each medical center or hospital may have any number of waiting rooms and any number of different types of procedure rooms. Each procedure room has particular medical equipment. Both the medical center and the hospital have pharmacies and laboratories represented implicitly in SimHCO, as well as accounting systems that track the costs of their services. The next sections provide more detailed descriptions of the components of the HCO facilities: the medical center, the hospital, the pharmacies and laboratories, and the accounting system.

Medical Center

The medical center receives patients through the appointment facilities, and provides outpatient care in the family practice, cardiology, and obstetrics / gynecology departments.

Appointment

Patient interactions with the medical center are through appointments. Members make appointments by either calling on the phone or by scheduling another appointment during an on-going appointment. The appointment department has a telephone queue and a schedule of available appointments in all rooms of the medical center.

Family Practice Department

The family practice department consists of waiting rooms and examining rooms. Patients come to family practice for diagnosis and treatment of ICD-9 diseases, cholesterol screening, diagnosis and treatment of minor chest pain, pregnancy diagnosis, prenatal exams, and diagnosis and treatment of HIV and related opportunistic infections. The family practice department admits patients to the hospital for acute chest pain, endangered pregnancies, and advanced HIV disease.

Cardiology Department

The cardiology department consists of waiting rooms and examining rooms. Patients come to the cardiology department on referral from the family practice department for diagnosis and treatment of high cholesterol and minor chest pain.

The cardiology department diagnoses and treats cardiac patients using electrocardiograms, treadmill electrocardiograms, and cholesterol-lowering drugs. The cardiology department admits patients to the hospital for more intense coronary care.

Obstetrics/Gynecology Department

The obstetrics / gynecology department consists of waiting rooms, examining rooms, and the high-risk pregnancy clinic. Patients visit the ob/gyn department for prenatal exams. Patients with high-risk pregnancies visit the high-risk pregnancy clinic. The ob/gyn department admits patients to the hospital for endangered pregnancies.

Hospital

The hospital receives patients through the admitting facilities, provides inpatient care in the family practice, cardiology, and obstetrics / gynecology departments, and provides emergency room service as well.

Admitting

Patients enter the hospital through admission during an examination at the health clinic or through the emergency room.

Family Practice Department

Patients enter hospital wards in the family practice department on referral from examination at the health clinic for the treatment of HIV and related opportunistic infections.

Cardiology Department

Patients enter the cardiology department on referral from examination at the health clinic or through the emergency room. The cardiology department diagnoses and treats cardiac patients using electrocardiograms, treadmill electrocardiograms, angiograms, thrombolitic drugs, angioplasties, and bypass surgeries. The cardiology department performs these procedures in cardiac care units, telemetry units, cardiac catheterization laboratories, medical / surgical units, and operating rooms.

Obstetrics/Gynecology Department

Patients enter the hospital either because they are in labor or on referral from examination at the health clinic. Patients in labor enter the ob/gyn labor rooms.

At the time of delivery or for a Cesarean section operation, they move to delivery rooms. After recovery, the mothers and babies move together to hospital wards in the ob/gyn department. If required, the babies may enter the neonatal intensive care unit.

Emergency Room

Patients enter the emergency room for acute chest pain or on referral from the examining room at the health clinic. The emergency room sends coronary patients to the cardiology department.

Laboratory and Pharmacy

The laboratories and pharmacies are modeled implicitly within the individual rooms -- SimHCO simply assumes that each room provides the appropriate lab test results and drugs.

Accounting System

The hospitals and medical centers collect and send co-payments from the members to the health plan. Each department of the hospitals and medical centers tracks the costs of resource-use by the members of the health plan. These costs include the costs of the rooms, equipment, supplies, and medical personnel. The hospitals and medical centers aggregate the costs of the departments and bill and receive payment from the health plan for their services.

Management and Clinical Policies

The policies database contains the management and clinical policies that govern the behavior of the HCO. The policies include screening policies (e.g. cholesterol screening programs), intervention policies (e.g. bypasses), and administrative policies (e.g. rate setting). The use of a database separate from the simulation allows the user to alter the policies during a simulation run without recompiling the code. The methods for accessing and changing policies are discussed in the "Policy Questions" section.

Medical Group

The phase II project will require individual physicians, specialists, nurse practitioners, nurses, aides, etc. who will examine, diagnose, and treat patients in inpatient and outpatient settings; admit and discharge patients from the hospitals; and bill the health plan for their services. In the phase I prototype, the medical personnel are modeled implicitly in the context of the hospitals and clinics. The decision-making processes of these personnel are represented by flow charts that have both probabilistic and deterministic branches. The costs of the services of the medical personnel are included in the facilities costs of the hospital and clinic rooms.

Event Queue

SimHCO models the interaction of people, diseases, and HCOs over a period of time as people age, change their behaviors, acquire diseases, have diseases that progress in time, seek and receive medical care, join and leave health plans, pay premiums to the health plan, and pay co-payments at hospital and health clinic visits. Everything that happens in the model can be described as an event.

The event queue controls, organizes, and processes the events, and thus drives a simulation run. The event queue keeps track of every event for every patient and processes them in chronological order. We explain the functionality of the event queue through an example of how the simulator processes an event for one person. For simplicity and clarity in the procedure, the example is an ICD-9 appointment for an individual Kaiser member, Julia Ann. Information in the population database at the start of the simulation run (1/1/96), tells us that Julia is a Kaiser member, 26 years old, single with no children, and has no risk factors for CAD or HIV. The population database also knows that Julia's next event is an ICD-9 event on March 18th at 2:37 p.m. for an injury (a mildly twisted ankle). The event queue contains the next event for every patient in the database.

SimHCO processes events in the event queue in chronological order. When Julia's ICD-9 event pops to the top of the queue, Julia calls for an appointment. The appointment phone has a queue filled with the other patients who are also trying to schedule appointments, so Julia waits on hold for three minutes as the others before her are processed. (Other events in the event queue are processed during those three minutes as well.) The appointment function determines that Julia called for an ICD-9 disease, and assigns her the next available ICD-9 appointment in an examining room in the family practice department (March 21st at 1:00 p.m. in Examining Room #5 in the Family Practice department of the Kaiser medical clinic). The simulator puts Julia's ICD-9 appointment event on the event queue, and continues processing events. When Julia's ICD-9 appointment event pops to the top of the event queue, she checks in at the waiting room for Examining Room #5. Examining room #5 happens to be free at 1:00 p.m., so Julia goes right in. The simulator determines stochastically that Julia's appointment takes 17 minutes, and schedules her departure on the event queue for 1:17 p.m. When Julia's appointment departure event pops to the top of the queue, the simulator determines from the disease models the time for Julia's next event (another ICD-9 event on July 17th at 6:23 p.m.), and schedules it on the event queue.

DISEASE MODELS

This section describes how diseases occur and progress within individual patients, the signs and symptoms and health outcomes of the diseases, and the diagnoses and interventions for the diseases. We begin with an overview of our disease modeling philosophy and the general structure of the disease models. We follow that with sections that document for each disease model a brief description and listings of the major components of the model. (Fully detailed descriptions of each of the disease models appear in the appendices.)

The disease models are a simplification of the actual disease progression. We concentrate on a small number of basic physical features that control or drive the progression of the disease. These basic physical features become the key variables of the models. For example, coronary artery disease is defined by the degree of occlusion of the coronary arteries, HIV/AIDS is defined by the number density of CD4+ T cells, the state of fetal development is defined by the fetal age, and so on. In this approach, following the state of the basic physical features is equivalent to following the progression of the disease. Most of the disease features vary continuously in time. Plaque slowly builds up in coronary arteries, tumors grow from small to large size, a fetus is conceived and develops to term, osteoporosis develops according to the deposition and loss of bone mineral density, the circulatory system degrades because of diabetes. Because these phenomena seem to slowly build up and smoothly vary in time, we model the disease progression as a continuous process. We write differential equations that describe the progression of these features in time, and connect all signs, symptoms and outcomes to these features. Because of this structure, the models can describe complex phenomena, contain many diseases, and quantify the effectiveness of a wide range of interventions and processes. Furthermore, the models are computationally simple because they track only a few variables.

Structure of the Models

The structure of the disease model makes it easy to add new signs, symptoms, diagnostics or treatments as they are developed or become important. The closer the disease model corresponds to the actual progression of the disease, the more likely it is that new interventions can be accommodated with little change. If the basic physical features defined in the model actually drive the disease progression, every treatment, intervention or diagnostic must be related to those features. Consequently, the only pieces that must be added to the model are the relations that link the basic features to the symptoms or diagnostic etc. If the new symptom or diagnostic is not related to the features we have already identified, then our original disease model was incomplete and we must reformulate it and include another basic feature that is related to the new sign, symptom or diagnostic.

Each disease model has two parts. The physical model describes the disease progression within the patient. The intervention model describes the actions of the medical personnel in diagnosing and treating a patient with the disease.

Physical Model

The physical model describes the disease progression within the patient. The physical model determines the beginning, progression, symptoms, and health outcomes of the disease. The disease trigger starts the progression of the disease. For example, pregnancy begins with conception; HIV begins with infection. The progression of coronary artery disease begins at birth, and thus does not have another trigger. After the occurrence of the disease trigger (if one exists), a set of differential and/or algebraic equations determines the progression of the basic physical feature and other related physical features. The risk factors affect the progression of these features. The signs and symptoms appear when the physical features reach threshold levels. These signs and symptoms affect the patient's quality of life and may cause the patient to seek care. The health outcomes listed are the final outcomes that people may attain without medical intervention.

Intervention model

The intervention model describes the actions of the medical personnel in diagnosing and treating a patient with the disease. The medical personnel gather information about the disease features and other physical features through the use of patient exams, interviews, and diagnostic tests. The medical personnel use the available patient information to make decisions about interventions. The interventions can affect the basic physical feature directly or the physical features that depend on the basic physical feature, other physical features, or the risk factors. The possible health outcomes are augmented based on the interventions. The model also tracks operational outcomes for the interventions.

Disease Model Documentation

The next four sections document for each disease model a brief description of the model and the main parts of the physical and intervention models. The purposes of this brief documentation are to show the components of the models and to highlight the similarity in the model structure for each disease. The brief documentation does not attempt to describe the interactions of the model components because that description requires the detailed text and equations contained in the accompanying report titled "Phase I Prototype Final Report: Part 2 - The Disease and HCO Selection Models."

Coronary Artery Disease (CAD) Model

The coronary arteries control the blood supply to the heart muscle. As the coronary arteries become occluded, the heart muscle receives less blood and oxygen. Mild oxygen deprivation

causes pain when the muscle is exerted. This is angina. Severe deprivation of blood and oxygen causes some part of the heart muscle to die. The greater the oxygen deprivation, the greater the fraction of heart muscle that dies. This is Myocardial Infarction (MI). Death of part of the heart muscle causes decreased capability to pump blood to other body parts. This in turn causes severe pain, inability to perform mechanical tasks, loss of blood to the brain, confusion and death.

The next sections describe the parts of the CAD model: the model of the physical process in the patient and the model of the interventions performed by the medical personnel.

CAD Physical Model

The CAD physical model models the physical process of CAD progression within the patient.

Model Trigger

The CAD model has no trigger -- the arteries begin occluding at birth.

Basic Physical Feature

For CAD the basic physical feature is the degree of occlusion (the patency) of the coronary arteries. The model tracks both slow occlusion, which causes chest pain, angina, myocardial infarction and death, as well as fast occlusion, which causes myocardial infarction and CAD death.

Dependent Physical Features

The occurrence of a myocardial infarction and the resulting amount of heart damage and fibrillation depend on the degree of occlusion.

Risk Factors

The risk factors for CAD are triglyceride level, HDL cholesterol level, LDL cholesterol level, total cholesterol level, systolic blood pressure, smoking, diabetes, gender, and age.

Signs and Symptoms

The signs and symptoms of CAD are the pain felt when the heart muscle is moderately deprived of oxygen, the severe pain and damage done when the heart muscle is severely deprived of oxygen and the resulting confusion, and death from lack of blood and oxygen to the brain.

Health Outcomes

The health outcomes of CAD are the following:

- Chest pain events
- Myocardial infarction events
- Fibrillation events
- Death

CAD Interventions

The CAD interventions model describes interventions that medical personnel may perform during the course of the disease. (Note that because SimHCO does not represent medical personnel explicitly, provider decisions are replaced by practice policy flowcharts with both deterministic and stochastic branches.)

Diagnostic Tests

The reading of an electrocardiogram, treadmill electrocardiogram or angiogram is related to the degree of patency of the arteries. The measured creatine level indicates the amount of heart damage.

Interventions that Affect Basic Physical Feature

The interventions that alter the degree of patency are the following: bypass surgery, angioplasty, and the administration of thrombolytic drugs.

Interventions that Affect Dependent Physical Features

The administration of thrombolytic drugs reduce the amount of heart damage and the probability of a fibrillation event.

Interventions that Affect Risk Factors

Interventions that reduce LDL-cholesterol are diet education and the administration of niacin. Anti-smoking education leads some patients to quit smoking.

Interventions that Affect Signs and Symptoms

The administration of nitroglycerin decreases chest pain.

Health Outcomes

The health outcomes of CAD are the following:

- Chest pain events
- Myocardial infarction events
- Fibrillation events
- Death

Operational Outcomes

The operational outcomes of interest are the number and cost of

- medical appointments
- hospitalizations
- bypass operations
- angioplasties
- thrombolytic drug treatments
- electrocardiograms
- treadmill electrocardiograms
- angiograms

Perinatal Care Model

The perinatal care model models pregnancy, labor, and childbirth. It describes the major events from conception to shortly after the birth of a child. All personnel, facilities, equipment, and supplies associated with these events are included. The model includes conception, change in maternal weight, change in maternal blood pressure, change in maternal glucose level (diabetes), development of symptoms of pregnancy (nausea, missed periods, weight gain, increase in hcG), development of fetus (weight, height, head circumference), development of congenital anomalies, development of symptoms of pre-eclampsia (high blood pressure, swelling, protein in urine), appointments with provider, gestation, labor and delivery. The conditions modeled include pregnancy induced diabetes, pregnancy induced hypertension, pre-eclampsia, eclampsia, congenital anomalies, complications of labor, vaginal delivery, cesarean delivery. Diagnostic tests include pregnancy tests, diabetes tests, blood pressure measurements, AIDS/HIV tests, amniocentesis, chorionic villus sampling, ultrasound, alfafetoprotein test, proteinuria test, fetal heart monitoring, non-stress test (NST), contraction stress test (CST) and biophysical profile (BPP). Facilities required include appointment making rooms, examining rooms, testing laboratories, labor rooms, delivery rooms, operating rooms, hospital rooms, neonatal intensive care unit (NICU), intensive care unit (ICU), Obstetrics and Gynecology clinic. Personnel include nurse practitioner, primary care physician, Obstetrics and Gynecology specialist, phlebotomist, registered nurse, labor and delivery room nurse. (Note that in SimHCO, medical personnel are modeled *im*plicitly. Their actions are modeled as practice policy flowcharts, with deterministic branches for standard practices and probabilistic branches for medical decisions. The costs of medical personnel are included in the costs of the hospital or clinic rooms.) Equipment includes ultrasound machine, testing equipment.

The perinatal care model divides naturally into two distinct models:

- the pregnancy model, which models the conception event, the development of the fetus, and the associated changes in the mother; and
- the labor and delivery model, which models the process of labor and delivery.

Each of these models has two parts: the model of the physical process in the patient and the model of the interventions performed by the medical personnel. The next sections describe the four parts of the perinatal care model.

Perinatal Care: Pregnancy Model

The pregnancy model models the physical process of pregnancy within the patient up to the start of labor.

Pregnancy Trigger

Conception triggers the pregnancy model.

Basic Physical Feature

The fetal age is the basic physical feature that characterizes the progression of the pregnancy.

Physical Features that Depend on the Basic Physical Feature

The fetal age drives the progression or occurrence of the following physical features:

- for the mother: extra maternal weight gain, extra maternal blood pressure, hcG level, extra maternal probability of diabetes, pre-eclampsia, eclampsia, swelling, nausea, missed periods
- for the fetus: weight, length, head circumference, metabolic reserves, congenital anomalies

Other Physical Features

Another physical feature of importance is the fetal lie.

Risk Factors

The following risk factors affect one or more of the physical features: maternal age, smoking, diabetes, alcohol and drug use, HIV status, hypertension, fetal gender, fetal congenital anomaly risk factor

Signs and Symptoms

The patient seeks care for weight gain, nausea, or missed periods, which initiate the diagnosis of pregnancy. During the pregnancy, the patient may seek care for swelling or nausea.

Health Outcomes

The health outcomes for pregnancy are

- Frequency and intensity of nausea attacks
- Maternal stroke due to eclampsia

- State of the fetus at the start of labor: congenital anomalies, fetal lie, metabolic reserves, and size
- Start of labor due to fetal age (which triggers the labor and delivery model)

Perinatal Care: Pregnancy Interventions

The pregnancy interventions model describes the practice policy flowcharts of the possible interventions by medical personnel during the course of the pregnancy up to the start of labor. (Note that because SimHCO does not represent medical personnel explicitly, provider decisions are replaced by practice policy flowcharts with both deterministic and stochastic branches.)

Diagnostic Tests

Pregnancy diagnostic tests include: hcG test; test of fetal lie; ultrasound to determine gestational age; diabetes tests; HIV test; proteinuria test; test of Rh factor; fetal heart monitor; MSAFP, CVS, and amniocentesis to diagnose congenital anomalies. For high-risk pregnancies, additional diagnostic tests include the non-stress test, the biophysical profile, and the contraction stress test, all of which measure the fetal metabolic reserves.

Interventions that Affect Basic Physical Feature

The fetal age stops progressing at the termination of the pregnancy. The pregnancy may be terminated by elective abortion, the induction of labor, a Cesarean delivery, or due to a spontaneous abortion caused by a CVS or amniocentesis.

Interventions that Affect Dependent Physical Features

The dependent physical features are modified by appropriate treatments: diabetes treatment, hypertension treatment, bed rest, nausea medication.

Interventions that affect other physical features

The physician can attempt to turn a fetus from the breech position.

Interventions that Affect Risk Factors

Counseling can affect smoking.

Health Outcomes

The health outcomes for pregnancy are

- Frequency and intensity of nausea attacks
- Maternal stroke due to eclampsia

- State of the fetus at the start of labor: congenital anomalies, fetal lie, metabolic reserves, and size
- Start of labor due to fetal age (which triggers the labor and delivery model)
- Elective abortion due to congenital anomalies
- Baby delivered by Cesarean section with the following possible health outcomes:
  for the mother
  - alive and well after Cesarean delivery
  - died because of Cesarean

  for the baby:
  - alive and well
  - alive with congenital anomalies (dependent on genetics and mother's risk factors)
  - alive with birth-related disability due to low metabolic reserves
  - alive with disability related to premature birth
  - died because of prematurity
  - died because of immaturity
  - spontaneous abortion
  - stillborn because of low metabolic reserves

Operational Outcomes

The operational outcomes for pregnancy are

- Number and type of prenatal exams for non-high-risk and high-risk pregnancies
- Number and type of prenatal diagnostic tests for non-high-risk and high-risk pregnancies
- Number of induced labors and Cesarean operations
- Number of elective abortions
- Number of treatments for diabetes, hypertension, preeclampsia, nausea
- Number of counseling sessions for smoking cessation

Perinatal Care: Labor and Delivery Model

The labor and delivery model describes the physical process of labor and delivery within the patient.

Labor Trigger

The labor and delivery model has two triggers: the fetal age reaching age at start of labor and the induction of labor

Basic Physical Feature

After delivery has begun, the cervical dilation characterizes the progression of the delivery.

Dependent Physical features

The cervical dilation drives the progression of the following physical features: length of labor and fetal descent. The length of labor drives the progression of the fetal metabolic reserves.

Risk Factors

There are no controllable risk factors that affect the physical features. (The maternal risk factors of smoking, alcohol and drug use, diabetes, and hypertension affect the starting point for the depletion of the fetal metabolic reserves, as described in the pregnancy model, but not their depletion during labor.)

Signs and Symptoms

The mother seeks care for labor pains or for the rupture of membranes.

Health Outcomes

The following are the possible health outcomes for the mother:

- Alive and well after vaginal delivery

The possibility of maternal death after vaginal delivery was not included in the perinatal model.

The following are the possible health outcomes for the baby:

- Alive and well
- Alive with congenital anomalies (dependent on genetics and mother's risk factors)
- Alive with birth-related disability due to low metabolic reserves
- Alive with disability related to premature birth
- Died because of prematurity
- Died because of immaturity
- Spontaneous abortion
- Stillborn because of low metabolic reserves

Perinatal Care: Labor and Delivery Interventions

The labor and delivery interventions model describes the interventions available to medical personnel during the course of labor and delivery. (Note that because SimHCO does not

represent medical personnel explicitly, provider decisions are replaced by practice policy flowcharts with both deterministic and stochastic branches.)

Diagnostic Tests

To monitor labor, the physician may use the following tests: fetal heart monitor and the biophysical profile. The physician also records the time since the onset of labor and can measure the cervical dilation and fetal descent. The physician knows the estimated fetal age and the patient's medical history and risk factors.

Interventions that Affect Basic Physical Feature

The administration of oxytocin increases the rate of cervical dilation; the administration of a tocolytic decreases or stops the rate of cervical dilation.

Interventions that Affect Dependent Physical Features

Cesarean delivery stops labor, and thus determines the length of labor and stops the cervical dilation and fetal descent.

Interventions that affect other factors

Baby length of stay in NICU affects the probability that the baby will have a disability related to premature birth.

Health Outcomes

The following are the possible health outcomes for the mother:

- Alive and well after vaginal delivery
- Alive and well after Cesarean delivery
- Died because of Cesarean operation

The possibility of maternal death after vaginal delivery was not included in the perinatal model.

The following are the possible health outcomes for the baby:

- Alive and well
- Alive with congenital anomalies (dependent on genetics and mother's risk factors)
- Alive with birth-related disability due to low metabolic reserves
- Alive with disability related to premature birth
- Died because of prematurity
- Died because of immaturity
- Spontaneous abortion

- Stillborn because of low metabolic reserves

Operational Outcomes

The operational outcomes for delivery are

- Cost of drugs during labor and delivery
- Cost of vaginal delivery + hospital stay
- Cost of Cesarean delivery + hospital stay
- Mother length of stay
- Baby length of stay in NICU

Human Immunodeficiency Virus (HIV) Model

The HIV model describes the major events associated with the disease including acquisition of HIV, progression of HIV, the infections that follow from HIV, the treatments and their effects, and the outcomes. All personnel, facilities, equipment and supplies are included. The opportunistic infections included are thrush, bacterial pneumonia, Pneumocystis carinii pneumonia (PCP), Toxoplasmosis (TOXO), and Cytomegalovirus (CMV). The treatments include PCP and CMV prophylaxes, AZT, Gancyclovir, Antibiotics, Fungicides. Tests include the enzyme immunoassay (EIA) and the Western blot, and various tests for the identification of opportunistic infections (OI). Facilities required include appointment making rooms, examining rooms, testing laboratories, hospital rooms. Personnel include family practice physician, nurse practitioner, care coordinator, phlebotomist. (Note that in SimHCO, medical personnel are modeled *im*plicitly. Their actions are modeled as practice policy flowcharts, with deterministic branches for standard practices and probabilistic branches for medical decisions. The costs of medical personnel are included in the costs of the hospital or clinic rooms.)

The next sections describe the parts of the HIV model: the model of the physical process in the patient and the model of the interventions performed by the medical personnel.

HIV Physical Model

The HIV physical model models the physical process of HIV progression within the patient.

Model Trigger

The HIV model is triggered when the patient becomes infected with the HIV virus.

Basic Physical Feature

After infection, the CD4 count characterizes the progression of the disease.

Dependent Physical features

The CD4 count drives the development of the five opportunistic infections: thrush, bacterial pneumonia, pneumocystic carinii pneumonia, toxoplasma infections, and cytomegalovirus. Related to the CD4 count is the "time constant," which drives the weight loss.

Risk Factors

Risk factors for infection include homosexual/bisexual orientation, intravenous drug use, and others. After infection, there are no risk factors that affect the progression of the disease.

Signs and Symptoms

The infected patient seeks care for weight loss or for symptoms of the opportunistic infections.

Health Outcomes

The health outcomes are a combination of the patient's length and quality of life. The quality of life depends on the occurrence of symptoms of the opportunistic infections and on the weight loss. The length of life depends on weight loss and the progression of the opportunistic infections and the underlying HIV infection.

HIV Interventions

The HIV interventions model describes interventions that medical personnel may perform during the course of the disease. (Note that because SimHCO does not represent medical personnel explicitly, provider decisions are replaced by practice policy flowcharts with both deterministic and stochastic branches.)

Diagnostic Tests

The tests to diagnose HIV infection are the EIA and Western Blot tests. The tests to diagnose the opportunistic infections are as follows: fungus measurement, bacterial pneumonia sputum test, PCP-confirming x-ray test, cerebrospinal fluid analysis, cytomegalovirus blood test and biopsy.

Interventions that Affect Basic Physical Feature

The drug AZT slows the depletion of the CD4 cells.

Interventions that Affect Dependent Physical Features

Treatments for the opportunistic infections include fungicide, penicillin, pentamidine, pyrimethamine, and gancyclovir. These treatments may be administered on an inpatient or outpatient basis.

Interventions that Affect Risk Factors

There are no interventions that affect risk factors in the model.

Health Outcomes

The interventions affect both the patient's length and quality of life. Treatment of the opportunistic infections relieves their symptoms and slows their progression, thus affecting both the length and quality of life. Treatment of the underlying HIV infection with AZT slows the depletion of the CD4 cells and thus lengthens the life of the patient, and indirectly slows the progression of the opportunistic infections.

Operational Outcomes

The operational outcomes for HIV are

- Number and length of HIV care hospitalizations
- Number of each type of diagnostic test
- Number of each type of drug treatment
- Costs of each of these outcomes

Other Diseases (ICD-9s)

All other diseases are included in the model at a very high level in order to add an appropriate load on the facilities. Other diseases are grouped according to the ICD-9 classifications:

- Infections and parasitic diseases
- Neoplasms
- Endocrine--metabolic diseases
- Disease of the blood
- Mental disorders
- Disease of the nervous system
- Diseases of the circulatory system
- Diseases of the respiratory system
- Diseases of the digestive system
- Diseases of the genitourinary system
- Complications of pregnancy
- Disease of the skin

- Diseases of the musculoskeletal system
- Congenital anomalies
- Conditions in the perinatal period
- Injury and poisoning
- Other and cross-cutting conditions

Physical Model

The occurrence of ICD-9 events is modeled as a stochastic process. Each patient has an ICD-9 event approximately three times per year (the time between ICD-9 events is chosen from an exponential distribution with mean 1/3 year). The type of ICD-9 event (which disease caused the event) is drawn probabilistically from national health statistics. The details and health outcomes of these events are not modeled explicitly.

Interventions Model

Each ICD-9 event requires an appointment in an examining room. The duration of the appointment is chosen from a normal distribution with mean 15 minutes and standard deviation 3 minutes. The actual interventions and their physical implications to the patient are not modeled explicitly. The operational outcome of interest is the number and cost of ICD-9 appointments.

HEALTH CARE ORGANIZATION SELECTION MODEL (CONJOINT MODEL)

Every HCO member belongs to a subscriber group, whether it consists of just himself or herself or includes other family members. In each of these groups there is a single *subscriber.* At the end of each fiscal year, the subscriber decides to which HCO the group will belong during the next year. The subscriber's decision is simulated with the HCO Selection Model. According to the HCO Selection Model, most subscribers simply remain at their current HCO and don't even consider changing to another HCO. For the subscribers that do consider changing, the probability of choosing a particular HCO depends on the subscriber's behavior characteristics and ideas about the relative importance of various factors such as costs, service, health outcomes, and an overall perceived "brand value" of the HCO. These behaviors and beliefs coupled with people's experience with an HCO contribute to their decisions about membership renewal each period. The HCO Selection Model we used was a proprietary model provided by Kaiser Permanente, and is described in more detail in Part 2 of the documentation.

POLICY QUESTIONS

The framework of SimHCO allows it to address policy questions. An analyst selects an HCO configuration, edits the policies, and examines the output reports.

HCO Configuration

The analyst selects an HCO configuration on the basis of the policy questions under consideration. For questions about one configuration of Kaiser, the analyst should configure SimHCO as **Kaiser**. For comparison of two different management or clinical policies, the analyst should configure SimHCO as **Kaiser vs Kaiser**. For questions involving market share and competition for members, the analyst should configure SimHCO as **Two HCOs** or **Four HCOs**.

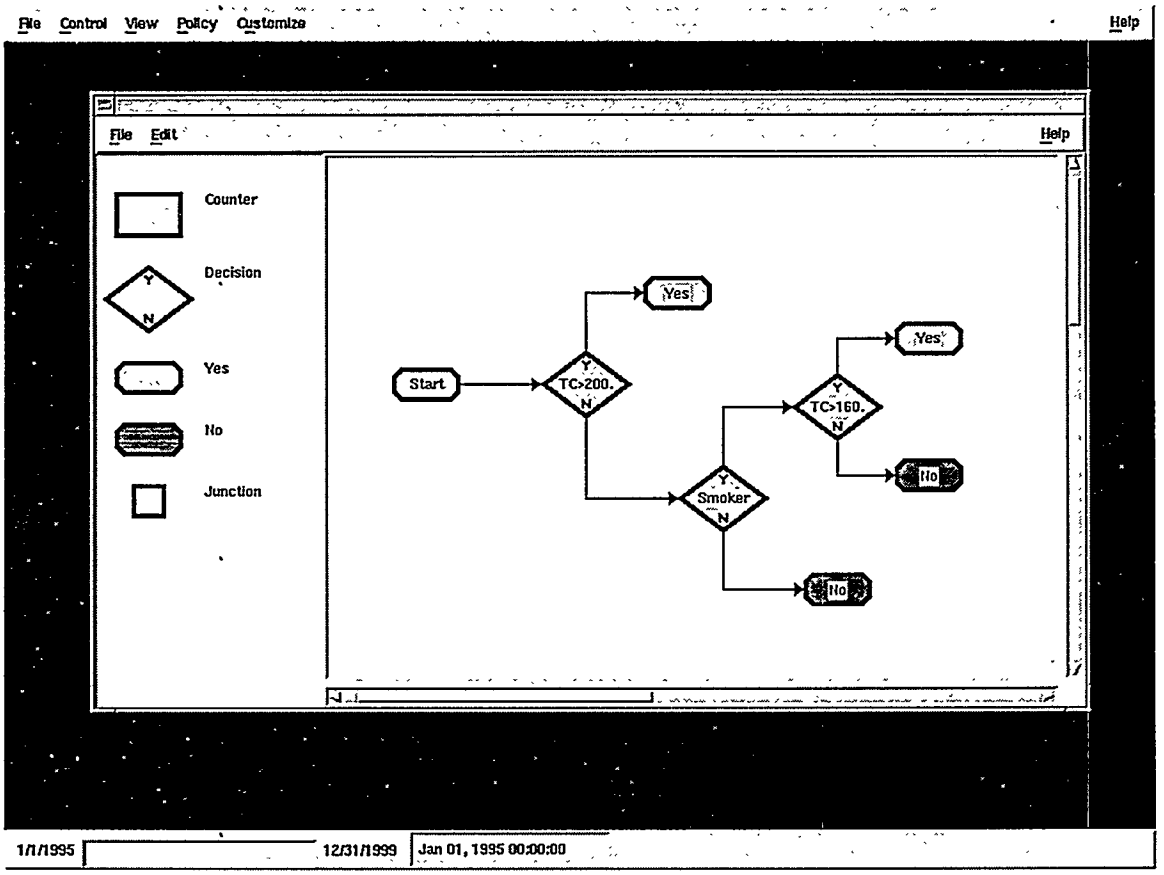
Policy Editing

There are two methods for the user to access and change policies: dialog boxes and policy editors.

In the Phase I version of SimHCO, most of the policy tailoring is done through dialog boxes, by typing values into text fields and selecting choices from lists. Examples of the information specified in this fashion include whether or not to screen for high blood pressure, the monthly premiums for single members, and all costs associated with intervention procedures such as bypasses and angiograms. Cholesterol screening programs can be tailored by specifying which patients should be screened, which patients (of those screened) should be treated, and the type of treatment to be administered.

The policy editor is a much more flexible tool. The Phase I prototype provides a policy editor for the cholesterol screening selection criteria. The user specifies the selection criteria in the form of a decision flowchart, similar to those used in clinical policy guidelines. See Figure 1 as an example. Directional flow from a decision box may depend on the answer to a question such as "Is the total cholesterol level of the patient greater than 180 mg/dL?" or "Is the patient a smoker?" This type of flowchart will be used for policy specification more often in the Phase II versions of SimHCO to offer greater flexibility and control to the user.

Figure 1. Policy Editor



Model Output Reports

At any time during a simulation, the user can inspect the state of the HCO and of its patients through viewers, graphs, and reports.

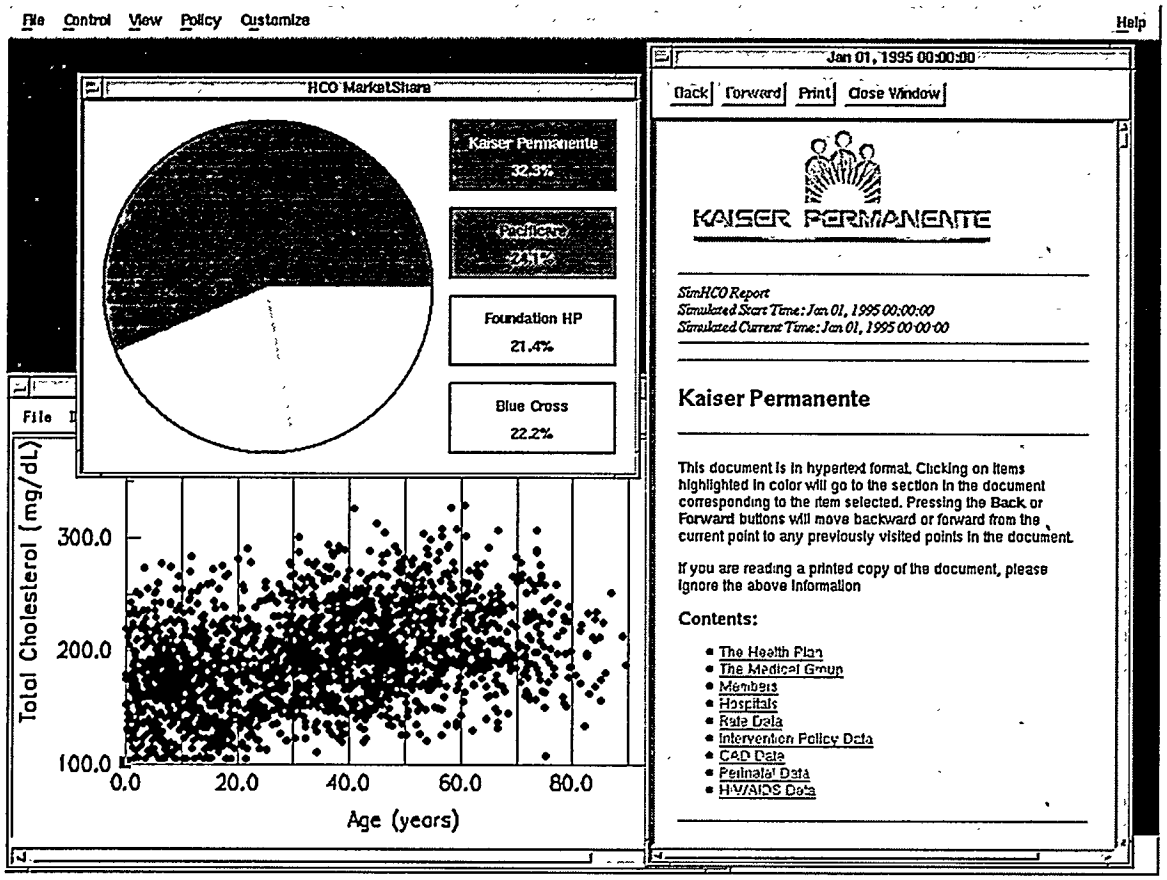
Viewers display the current values of all attributes of the object of interest. For example, a patient viewer shows his or her name, age, and all health indicators such as blood pressure or cholesterol level. These viewers are dynamic: they are updated as the simulation advances in time.

A number of graphical outputs can be produced during the simulation. A pie chart showing the relative numbers of members in each HCO can be used to track the "market share" of the HCOs. A bar graph breaks down the market share even further according to subscriber group type (single, couple, or family). As with viewers, the market share graphs are updated as the simulation advances. Static histograms and x-y plots can be shown for the patient population, based on any of the attributes of the patients. For example, the user can produce a plot of total cholesterol level vs. age for all males who are smokers and are diabetic.

Reports can be produced for any of the facilities within the HCO, including the HCO as a whole. These static reports display cumulative statistics, such as the number of patients seen at

this facility during the simulation, as well as information about the current state of the facility. The reports are formatted as HTML documents, making them very easy to browse. As an example, see Figure 2.

Figure 2. Example model output report



MODEL EXTENSION: THE OBJECT-ORIENTED DESIGN

The Kaiser Heath Care Model is implemented using a software technology known as object-oriented programming. In this section, we will give an overview of object-oriented programming and its benefits for the Kaiser model.

Object-oriented programming is a relatively new software technology. Although originally introduced nearly 30 years ago, it was rarely used until about 10 years ago and it is only within the last 5 years that it has become widely used. Object-oriented programming has 3 main benefits in the context of the Kaiser model. These benefits (classes, encapsulation, and inheritance) will be described in the next three sections.

Classes and objects

The first benefit of the object-oriented paradigm is that software is organized into units called *classes*. Each class directly represents some real world category, for instance in SimHCO we have classes called PATIENT and HCO, among others. (We use uppercase for class names). In Phase I, SimHCO does not have the class DOCTOR, but Phase II will have such a class, and we use this class for illustrative purposes in this section. Class DOCTOR contains both the data and the code to represent the state and behavior of the general physician. When the Kaiser model is running, class DOCTOR is used as a template to create as many doctor objects as needed. We say that each doctor object is an *instance* of class DOCTOR. Each doctor object is a complete, self-contained model of a physician.

This organization of software is especially beneficial to the Kaiser model because it helps maintain a strong and obvious connection between each piece of software and its purpose and function within SimHCO. A newly hired programmer would have little confusion about what class DOCTOR is supposed to represent or where to go in the code to change the behavior of doctors. The class structure thus contributes to effectively maintaining and extending SimHCO.

It is useful to contrast this object-oriented organization with the older, so-called procedural programming paradigm. In the procedural paradigm, software is separated into data and procedures that operate on the data. The implementation of doctor would typically be scattered into several data structures and several procedures, making it difficult to understand and change.

Encapsulation

The second benefit of the object-oriented technology is called *encapsulation*. Encapsulation refers to the fact that each object is self-contained and its internal implementation is hidden from other objects that refer to it. For instance, in SimHCO, doctor objects can be found in examining

room objects. The code that implements the examining room object refers to a doctor object, but does not contain any reference to the internal implementation of the doctor object.

Encapsulation substantially reduces the effort required to maintain and extend SimHCO because it limits the effect of changing a part of the model. Changes to the implementation of a given class typically do not force changes to the classes that refer to it, because those classes have no knowledge of how the given class is implemented.

We can also contrast encapsulation with the procedural programming style. The data structures in the procedural style are not encapsulated and are typically referred to by many procedures. Changing a data structure forces changes to wide-spread parts of the software.

Inheritance

The third and final benefit we will discuss is referred to as *inheritance*. Inheritance provides an efficient programming mechanism for extending or *specializing* a class. For instance, suppose we need to extend the Kaiser model to contain surgeons in addition to general physicians. Now a surgeon is a special kind of physician and can do everything a physician can do, plus more. When programming class SURGEON we would like to avoid duplicating all the code from class DOCTOR. Inheritance provides the mechanism. The programmer inserts a single line of code in class SURGEON, stating that it inherits class DOCTOR. Each surgeon object then has all the features of a doctor object, plus any additional features that are programmed directly in class SURGEON. Furthermore, since a surgeon object is now a special kind of doctor object, and has all the features of a doctor object, it can be used in anywhere a doctor object is required. Thus, after adding class SURGEON, the programmer does not have to change any existing code to make it accept the surgeon objects. Without any changes, an examining room object can accept a surgeon object because a surgeon object is a (specialized) doctor object.

Like classes and encapsulation, inheritance also makes SimHCO easier to maintain and extend and it does so in two ways. Like the organization into classes, it helps maintain a clear connection between the structure of the code and the real world. Surgeons really are specialized doctors. And like encapsulation, it helps minimize the propagation of changes from one part of the code to another. Introducing a specialized doctor does not force any changes to examining rooms.

Summary

Object-oriented programming technology is very well suited to implementing the Kaiser Health Care Model and helps make the software easier to understand, maintain, and extend.

MODEL COMPUTATIONAL PERFORMANCE

This section describes the scaling behavior of the Kaiser/Sandia Health Care Simulator as a function of the number of people, number of diseases and length of simulation.

The main loop in the program goes as follows:

```
while() {
        Pull next event from main queue
        Perform procedure on person
        Project person forward to next event
        Place event on main queue
}
```

The main effort in the code can be broken into three areas. The most important one is:

T_1 : Projecting person forward, by updating physiology and performing treatments

Two minor factors are:

T_2 : Sorting main queue.

T_3 : Sorting individual queues.

The total CPU time used is approximately

$$T_{total} \approx T_1 + T_2 + T_3$$

The following variables are used in the discussion below:

N_{years} = number of years the simulation is run.

N_{people} = number of people in population

N_D = number of diseases

n_j = number of events for a disease j in a year for a person with that disease

ρ_j = probability that a person will have disease j in a given year.

c_j = average CPU time for an event for disease j.

Estimating T_1:

The total number of events in one year for one person, assuming no interaction between events is:

$$n^0_{events} = \sum_{j=1}^{N_D} \rho_j \, n_j \qquad (2$$

If we assume that a fraction of events cause some number of other events to be redone, then the number of events for one person for one year is approximately:

$$n_{events} = n^0_{events}(1 + \alpha \, n^0_{events}) \qquad (3)$$

where α is a measure of this coupling. The total number of events in a simulation of N_{years} years for N_{people} people is given by:

$$N_{events} = N_{years} \; N_{people} \; n_{events} \qquad (4)$$

The corresponding CPU times are given by

$$\bar{c}^0 = \sum_{j=1}^{N_D} c_j \rho_j \, n_j \qquad (5$$

which is the CPU time for one person for one year, assuming no coupling between diseases.

$$\bar{c} \; = \bar{c}^0 \, (1 + \alpha \, \bar{c}^0) \qquad (6$$

is the CPU time assuming coupling at level α, and

$$T_1 = N_{years} \; N_{people} \; \bar{c} \qquad (7$$

is the total CPU time associated with projecting events forward in a simulation of N_{years} years for N_{people} people. Parameters will be estimated below.

Estimating T_2:

The total number of events, and therefore the total number added to the queue, is given by equation 4. The main queue holds N_{people} events at an one time. The cost of adding each event is $\log(N_{people})$ so the total cost of handling the main queue is then:

$$T_2 = \delta \; N_{years} \; N_{people} \; n_{events} \log(N_{people}) \qquad (8)$$

where δ is the cost of adding an event to the queue.

Estimating T_3:

The average number of events on the individual queues at any given time is a fraction of the total events a person experiences in a year. Few events are scheduled as much as a month in advance, so we will use a factor of 0.1. The cost of adding an event is the log of the length of the queue. All events are added eventually, so the total cost is given by:

$$T_3 = \delta\, N_{years}\, N_{people}\, n_{events} \log(0.1 \times n_{events}) \qquad (9$$

Estimating T_{Total}:

The total cost is then given by

$$T_{total} = N_{years}\, N_{people} \times \left[\bar{c} + n_{events}\, \delta \left\{\log(N_{people}) + \log(0.1 \times n_{events})\right\}\right] \qquad (10)$$

We can make a first simplification by examining the relative costs of the projection and queue manipulation terms. If we assume that every patient event costs the same ($c_j = c_{avg}$) then Eq. 10 can be simplified to

$$T_{total} = N_{years}\, N_{people}\, n_{events} \times \left[c_{avg} + \delta \left\{\log(N_{people}) + \log(0.1 \times n_{events})\right\}\right] \qquad (11)$$

The costs c_{avg} and δ are given by the average time to perform an arithmetic operation, times the corresponding number of arithmetic operations required. The operation associated with a δ event is essentially a single comparison (e.g. is a<b?). The corresponding operation associated with a c_{avg} event is much more complex, involving for instance the solution of a differential equation. At no time will the population get so large that the log terms will affect the relative costs of the terms very much. Therefore for the subsequent analysis, we will assume that the cost of projecting patients forward will dominate, and the effect of the queue manipulation terms will be neglected.

In order to estimate the parameters which come into this equations, a number of simulations were run with differing numbers of people and different sets of diseases. The machine we used for the simulation runs was a 200 MHz Pentium Pro (P6) with 64 Mbytes of memory, running LINUX and the GNU g++ compiler. Except for some minor start up costs, the simulation time and number of events scale linearly with the number of years run. Each run described below was followed for 10 years. We performed 15 timing runs varying both the number of people in the

simulation (2000, 10000, or 21007 people) and which the disease models were included (ICD9 alone, ICD9 + CVD, ICD9 + Perinatal, ICD9 + AIDS, or ICD9 + CVD + Perinatal + AIDS). For each run, we record the total number of events (both patient and hospital events) per year and the total CPU time per year.

Table 1 - **Results as a function of number of people**

ICD9	CVD	Perinatal	AIDS	N_{events} (number / 10)			T_{Total} (CPU seconds / 10)		
				5000	10000	21007	5000	10000	21007
x				54385	108752	227955	6.40	13.37	29.30
x	x			54413	109263	228853	7.08	14.50	31.36
x		x		60074	119105	251487	7.60	15.71	34.04
x			x	54526	108694	228439	6.42	13.33	28.87
x	x	x	x	60051	119544	251487	8.70	17.84	38.36

Each row of Table 1 indicates which set of disease was included. The results for the runs in the 3 sizes are included next to one another. The major point to be made here is that the CPU time and number of events scales linearly with the number of people. For further analysis, we will restrict attention to the largest runs using 21007 people. Table 2 gives additional information for these runs.

Table 2 - **Results for 21007 people runs**

ICD9	CVD	Perinatal	AIDS	$\bar{N}_{CVD}$	$\bar{N}_{preg}$	$\bar{N}_{AIDS}$	T_{Total} (CPU sec/10)	N_{events} (number / 10)
x				0	0	0	29.30	227955
x	x			21007	0	0	31.36	228853
x		x		0	1995	0	34.04	251487
x			x	0	0	11.8	28.87	228439
x	x	x	x	21007	1994	12.8	38.36	251487

The quantities $\bar{N}_{CVD}$, $\bar{N}_{preg}$, and $\bar{N}_{AIDS}$ are the average number of people who had CVD, a pregnancy or AIDS respectively, in a given year. Everyone has CVD so the number here is the total population. The quantities ρ_{AIDS} and ρ_{preg} are given by dividing $\bar{N}_{AIDS}$ and $\bar{N}_{preg}$ by the population size. (For a conservative estimate, we used the larger numbers.) The value of ρ_{CVD} is 1.0.

$$\rho_{CVD} = 1.0$$
$$\rho_{preg} = 0.0950$$
$$\rho_{AIDS} = 0.0006$$

The next quantity we require is the number of events per person per year for each of these diseases. To get these, we subtract the total number of events for the run with disease j (either CVD, perinatal, or AIDS) from the total number of events for the run with just ICD9. If we assume no coupling between ICD9 and any of the other 3 diseases, then

$$N_{events}(ICD9+j) - N_{events}(ICD9) = N_{years}\, N_{people}\, \rho_j\, n_j \tag{12}$$

From this equation, and the data in Table 2, we get the following values:

$$n_{CVD} = 0.0427$$
$$n_{preg} = 11.79$$
$$n_{AIDS} = 38.40$$

We can perform the same analysis in CPU times to get the average cost per event for each of these diseases, using the equation

$$T_{total}(ICD9+j) - T_{total}(ICD9) = N_{years}\, N_{people}\, c_j\, \rho_j\, n_j \tag{13}$$

The resulting values are then

$$c_{CVD} = 0.00229$$
$$c_{preg} = 0.000201$$
$$c_{AIDS} = -0.000888$$

(The reason that c_{AIDS} is negative is that AIDS and natural deaths reduce the population size, so there are fewer people to update and process, and the additional computational burden of the AIDS calculations do not compensate for the reduction.)

At this stage, we can estimate the non-linearity parameter by using the parameter values estimated for the three diseases, predicting the number of events and total CPU time for the run with all diseases, and comparing this prediction with that actually obtained from that run.

$$\begin{aligned} &N_{events}(ICD9+CVD+perinatal+AIDS) - N_{events}(ICD9) = \\ &N_{years}\, N_{people}\, n^0_{events}(CVD+perinatal+AIDS) \times \left\{1+\alpha\, n^0_{events}(CVD+perinatal+AIDS)\right\} \end{aligned} \tag{14}$$

where $n^0_{events}(CVD+perinatal+AIDS) = 1.186$, calculated from Eq. 2 using the parameters just derived. The corresponding equation can be used for CPU times (where we calculated $\bar{c}^0(CVD+perinatal+AIDS) = 0.000303$ from Eq. 5). Using these, we arrive at the following values of α:

$$\alpha(\mathrm{N}) = -0.0468$$
$$\alpha(\mathrm{T}) = 1397$$

Similarly, we can estimate α(N) and α(T) for all three population sizes. In the table, we use the following notation:

$$TotalEvents = N_{events}(ICD9 + CVD + perinatal + AIDS) - N_{events}(ICD9)$$

$$CalculatedEvents = N_{years}\, N_{people}\, n^{0}_{events}(CVD + perinatal + AIDS)$$

Calculation of alpha(N)

Population Size	5000	10000	21007
Total Events	56660	107920	235320
Calculated Events	59300	118600	249143
alpha(N)	-0.0375	-0.0759	-0.0468

Calculation of alpha(T)

Population Size	5000	10000	21007
Total Events	23	44.7	90.6
Calculated Events	15.15	30.3	63.7
alpha(T)	1710	1568	1397

The α(N) estimates are negative because adding events for a new disease occasionally causes previously scheduled events to be canceled. The α(T) estimates reveal another story: additional diseases add total CPU processing time in a non-linear fashion. We speculate that the additional diseases cause additional start-up costs for the simulation. This theory is consistent with the decrease in α(T) as the population size increases. We assume that as the problem size goes up, the coupling tends toward zero.

For the remaining calculations, we use the coupling factor

$$\alpha = \alpha(\mathrm{T}) = 1397$$

We are now set to predict the CPU time for simulations with larger numbers of diseases. We assume that we have 80 diseases, one third of which have the same parameters as each of the three diseases considered so far. The total CPU time for a 1 year simulation with 2,000,000 people in this case is

$$\bar{c}^{0} = \frac{80}{3}\left(c_{CVD}\,\rho_{CVD}\,n_{CVD} + c_{preg}\,\rho_{preg}\,n_{preg} + c_{AIDS}\,\rho_{AIDS}\,n_{AIDS}\right) = 0.00808 \qquad (15)$$

$$\bar{c} = \bar{c}^{0}\left(1 + \alpha\,\bar{c}^{0}\right) = 0.0993 \qquad (16)$$

$$\begin{aligned} T_{total} &= 2{,}000{,}000 \times \bar{c} \\ &= 198{,}610\,\mathrm{sec} = 55.2\,hours \end{aligned} \qquad (17)$$

This value provides an estimate of the CPU time required for 1 year of simulation time on a 200 MHz Pentium Pro (P6) machine running LINUX. Based on extrapolating past performance gains, we can predict that the fastest workstations in 5 years will be 18-25 times faster than the P6, so the target simulation will be able to be run in 2.2 to 3.1 CPU-hours per year of simulated

time. This leads to 44.1 to 61.3 CPU-hours for a 20 year simulation. We anticipate that it will be possible to take advantage of shared memory multiprocessor machines, with a relatively small number of processors (~32) without large changes in the underlying discrete event methodology. This would reduce the wall clock time to about between 1.4 and 1.9 hours for a 20 year simulation. Thus, we predict that the Phase II model will run within the system constraints of modern computer technology.

Memory Issues:

We may have to develop more sophisticated memory management techniques for simulations as large as those being contemplated. The memory requirements scale as the number of people times the number of diseases. Additional storage is required if patient information must include detailed history. Assume that every one of the 80 diseases requires us to store 10 variables to describe the current state, and 10 variables to describe the history, and that people only get about 10% of diseases. This then requires about $2{,}000{,}000*10*10*80/10 = 1.6 \times 10^9$ words of memory or 12 Gbytes. Current machines, such as the R8000, use 1 Gbyte. Machines handling 5Gbytes are currently available, so it is likely that machines will be available in 5 years that support on the order of 12-15 Gbytes. Current drops in memory prices support this conclusion.

CONCLUSION

Phase I accomplished its purpose and objectives. SimHCO is a working prototype computer model that contains a few examples of each important system element: multiple health care facilities, three detailed diseases (coronary artery disease, perinatal care, and human immunodeficiency virus / acquired immune deficiency syndrome), several reduced detail (ICD-9) diseases, and one management problem (rate setting in the context of the HCO Selection Model for how people select their HCO). The project team selected the components of the prototype through the domain analysis of the system, and determined that the detailed models combined by a high-level structure would address interesting and important clinical and managerial questions. The team developed and parameterized complex, interacting, statistically accurate disease models, and described the health care facilities and personnel required in the treatment of these diseases. The team designed the model as a discrete-event simulation that explicitly tracks the time progression of the physiological attributes (weight, height, arterial occlusion, CD4 cell count, etc.) of each patient, the prescription of treatments and outcomes of diseases in each patient, the resource usage by each patient, and patient choices in a competitive environment, for populations of up to 100,000 members. The team implemented SimHCO in the object-oriented programming language C++, stressing reusable knowledge and reusable software components. The versioned implementation of SimHCO showed that the object-oriented framework allows the program to grow in complexity in an incremental way without having to reprogram existing features. Furthermore, timing runs showed that SimHCO runs in a reasonable time on typical workstations, and that the Phase II model will scale proportionally and run within the system constraints of modern computer technology.

APPENDIX. BRIEF USER'S GUIDE

The Brief User's Guide contains a Tutorial section that includes a sample run, and a Reference section that describes the functionality of each of the menu items.

A. Tutorial

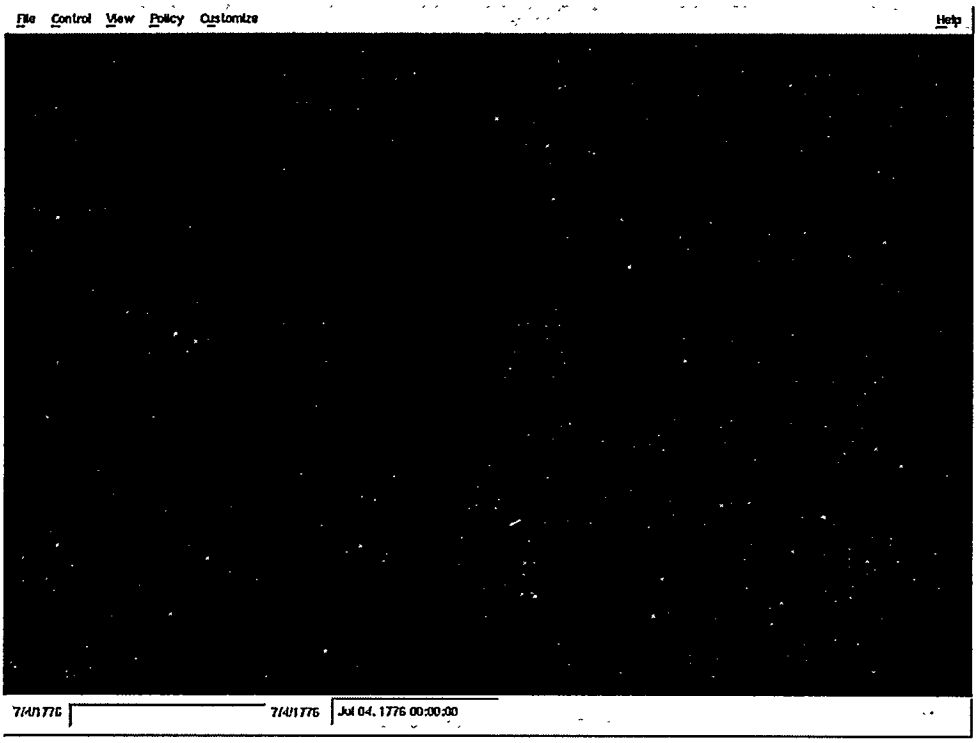
In this section, we describe how to run SimHCO using its graphical user interface. Along with a general tutorial, we also describe a specific sample run in which we investigate the consequences of implementing a cholesterol screening program. This sample run involves the simulation of two HCOs which are identical except that one has a screening program and the other does not.

Before running a simulation, we must first specify the overall configuration. This includes the number of HCOs to be simulated and the HCO descriptions. Using the left mouse button, click on the screen background, then drag while keeping the mouse button depressed. A toolchest menu will appear. Highlighting **Kaiser Demos** will bring up the four configurations of SimHCO: **Kaiser** (a simulation of a Kaiser Permanente HCO), **Kaiser vs Kaiser** (a simulation of two initially identical Kaiser Permanente HCOs for policy evaluations), **Two HCOs** (a simulation of a Kaiser Permanente HCO competing for members against Pacific Care), and **Four HCOs** (a simulation of a Kaiser Permanente HCO competing for members against Pacific Care, Blue Cross, and Foundation Health Plan). For our sample run, we choose **Kaiser vs Kaiser**.

After selecting a configuration the main board for SimHCO appears (Figure A1). At the top of the main board is a menu bar which contains all commands to control and view the simulation run. At the bottom of the main board is a status bar which reflects the current run status and simulation time. The functionality of each of these menu items is described in full in the Reference section.

We now specify a patient population by selecting **Select Patient Database** from the **File** menu. The selector dialog that appears lists the filenames of available patient databases. Choose a particular database by clicking on the filename to highlight it, then hitting the **OK** button. For our sample run, we select "patients.2x1000." In this database, patients with identification numbers from 0 through 999 are identical to patients 1000 through 1999 except that the first thousand patients belong to Kaiser Permanente 1 (KP 1) while the second belong to Kaiser Permanente 2 (KP 2).

Figure A1. Main board for SimHCO



The message "Done Loading Patients" appears after the database is read and SimHCO is initialized.

At this point, the current simulation time is the time associated with the chosen patient database (January 1, 1995 in our example). This time is displayed on the right side of the status bar at the bottom of the main board.

Individual patients can be inspected at any time by selecting **Find Patient** from the **View** menu, then entering the identification number of the patient of interest. Clicking on the **Find Patient** button will bring up a viewer of the patient (Figure A2). In our example, we open a viewer for patients with identification numbers of 976 and 1976. Inspection confirms that the patients are identical, except for the fact that patient 976 belongs to KP 1 while patient 1976 belongs to KP 2. We also open a monitor for each patient by clicking on the **Show Monitor** button on each of the patient viewers. When the simulation is run, descriptions of the events that occur to the patients will show up in their respective monitors.

The status of the HCOs can be inspected at any time by selecting **Open Browser** from the **View** menu. In our sample run, the browser displays icons representing the two HCOs, **Kaiser Permanente 1** and **Kaiser Permanente 2**. Clicking on these icons displays viewers for the respective HCOs (Figure A3).

Figure A2. Patient Finder, Viewers, and Monitors

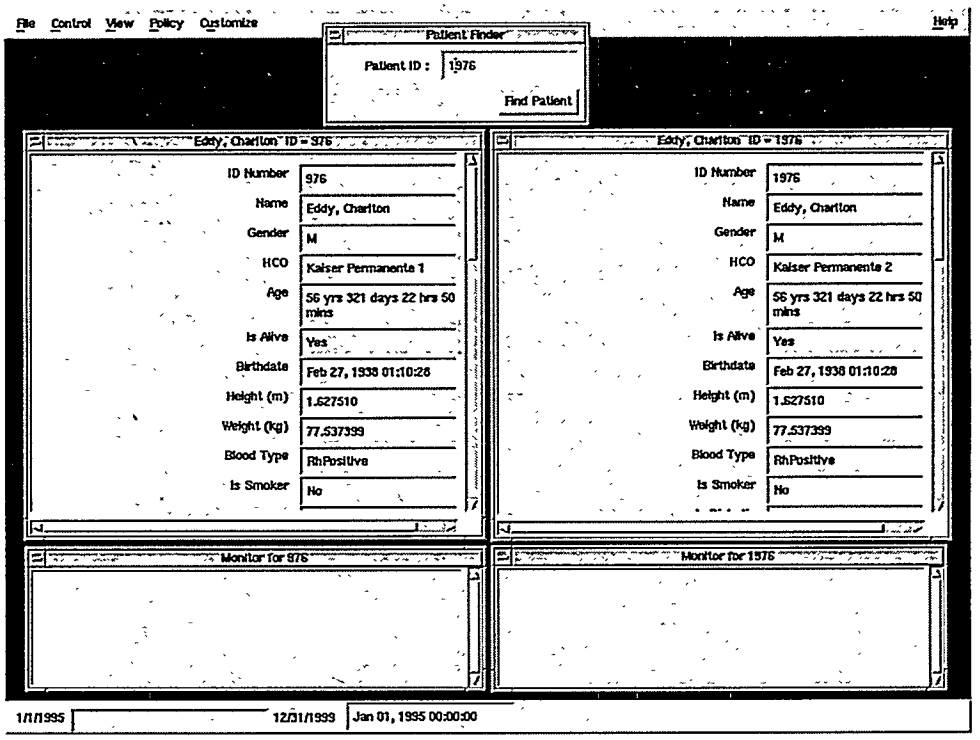
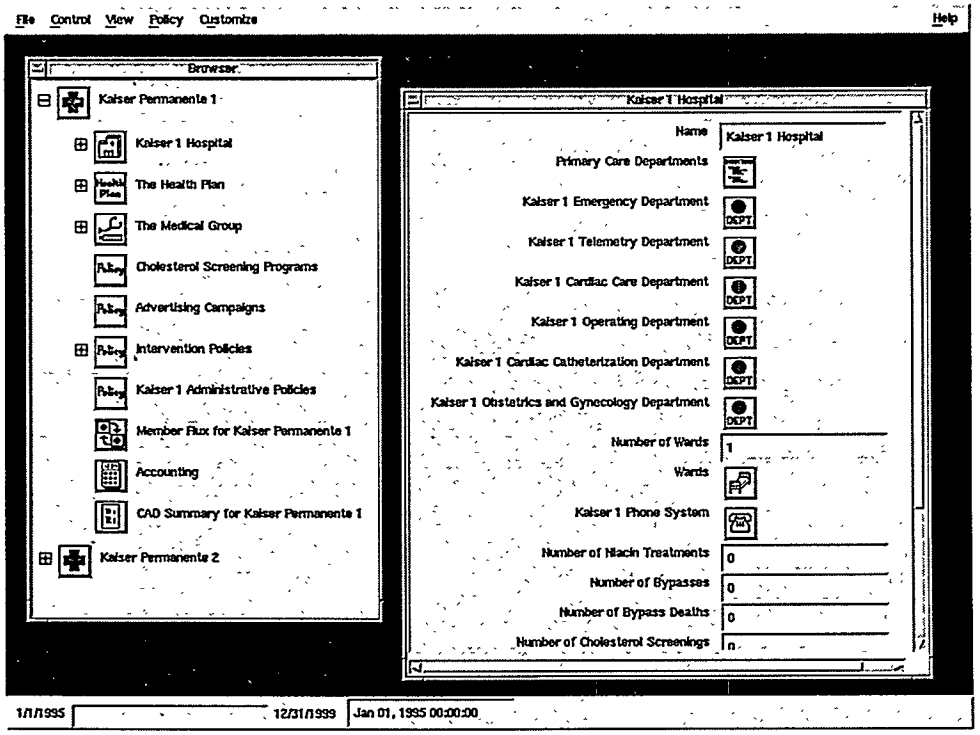


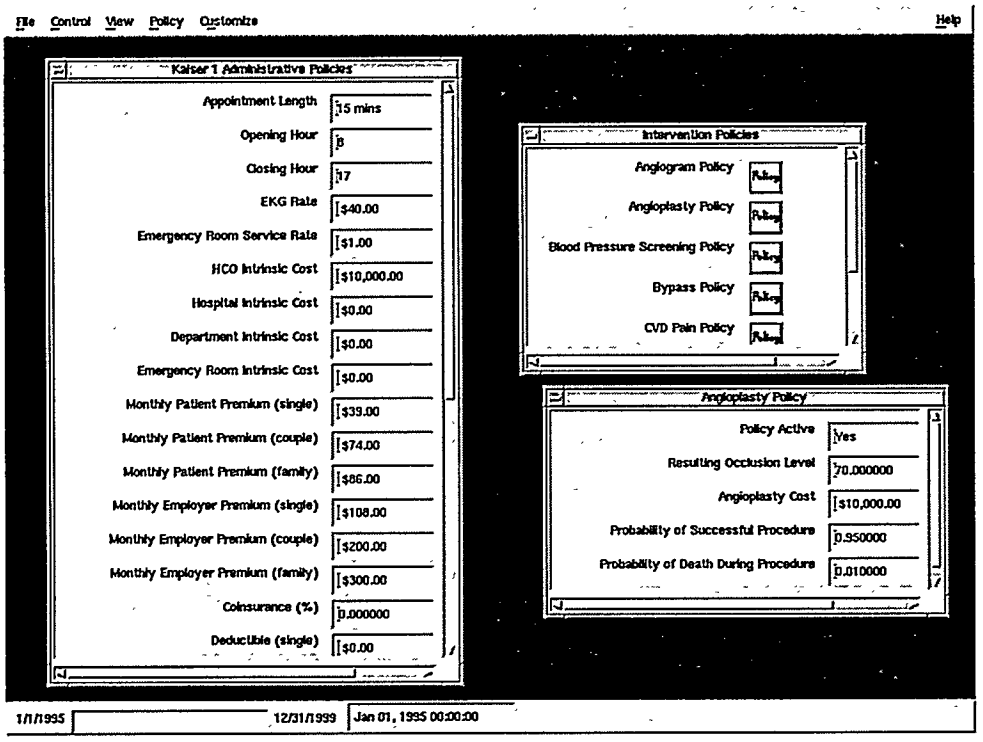
Figure A3. Browser and Viewer for HCOs



We can affect the behavior of the HCOs by changing the policies that govern them. Administrative policies, including premium and copayment levels and average waiting times, can be accessed through the **Administrative Policies** found in the HCO viewer (Figure A4). Various intervention policies can be specified by first opening the viewer for **Intervention Policies** from the HCO viewer, then opening the viewer for the specific policy (for example **Angioplasty Policy**).

If we open the viewers for **Cholesterol Screening Programs** or **Advertising Campaigns** we find that they are empty: in the default configuration, no programs exist. We can create programs to be implemented during the simulation by selecting **Programs/Campaigns** from the **Policy** menu, then indicating for which HCO we are creating the program and the type of program (cholesterol screening or advertising).

Figure A4. HCO administrative policy



For our sample run, we create a cholesterol screening program for KP 2, leaving KP 1 unchanged to serve as a baseline. After selecting **Programs/Campaigns**, indicating **Kaiser Permanente 2**, and clicking on **Cholesterol Screening Program**, we are presented with a dialog box in which we can design our screening program (Figure A5). We keep the default parameters for determining which patients will be notified, but change the **Notification Date** to Jan 1, 1995. We also specify the criteria for deciding who will be treated by clicking on **Select New**

Flowchart, then selecting "ncep.dfc" from the list. Finally, we hit the **Accept** button to create the screening program. If we now open the viewer for KP 2's Cholesterol Screening Programs, we find an icon for the program just created, and can review the program by clicking on the icon to open a viewer.

Patient selection flowcharts represent criteria for choosing patients based on a combination of patient attributes. We used the flowchart named "ncep.dfc" for determining which patients should receive treatment in our cholesterol screening program. Flowcharts can be created and inspected by selecting **Patient Selection Flowcharts** from the **Policy** menu to open the flowchart editor. To view "ncep.dfc," we select **Open** from the **File** menu of the flowchart editor, then select "ncep.dfc" from the list of flowcharts (Figure A6). New flowcharts can be created and existing ones can be edited then saved with the flowchart editor. These saved flowcharts then serve as candidates for the treatment decision criteria for cholesterol screening programs. In Phase II of SimHCO, more of the selection and decision criteria will be tied to these types of flowcharts to increase the user's flexibility in controlling policies.

Figure A5. Cholesterol Screening Program

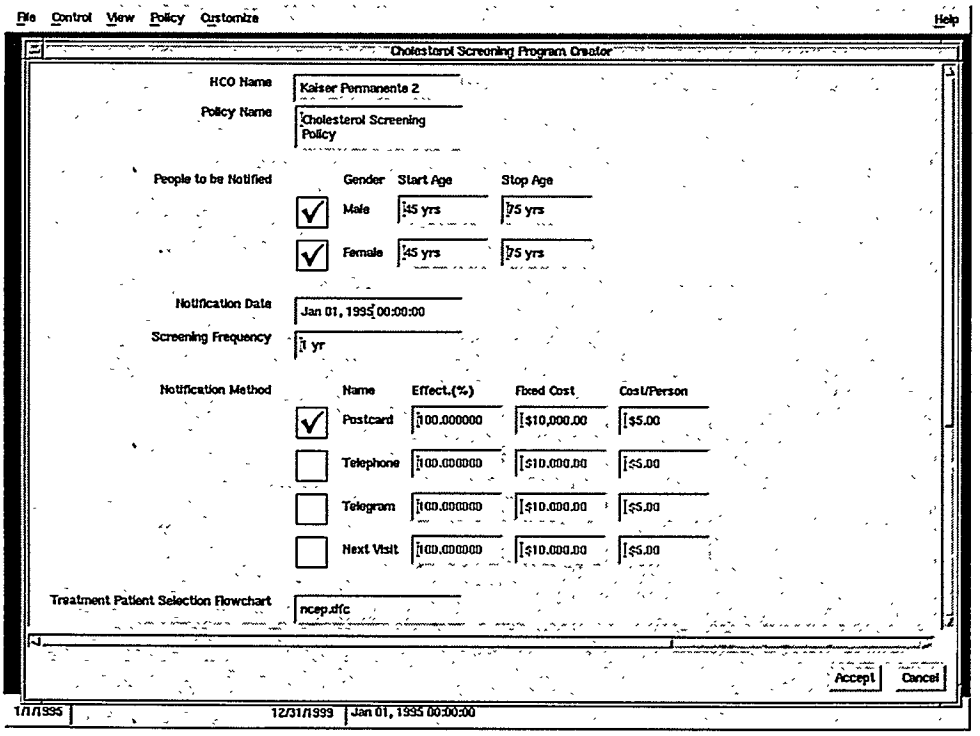
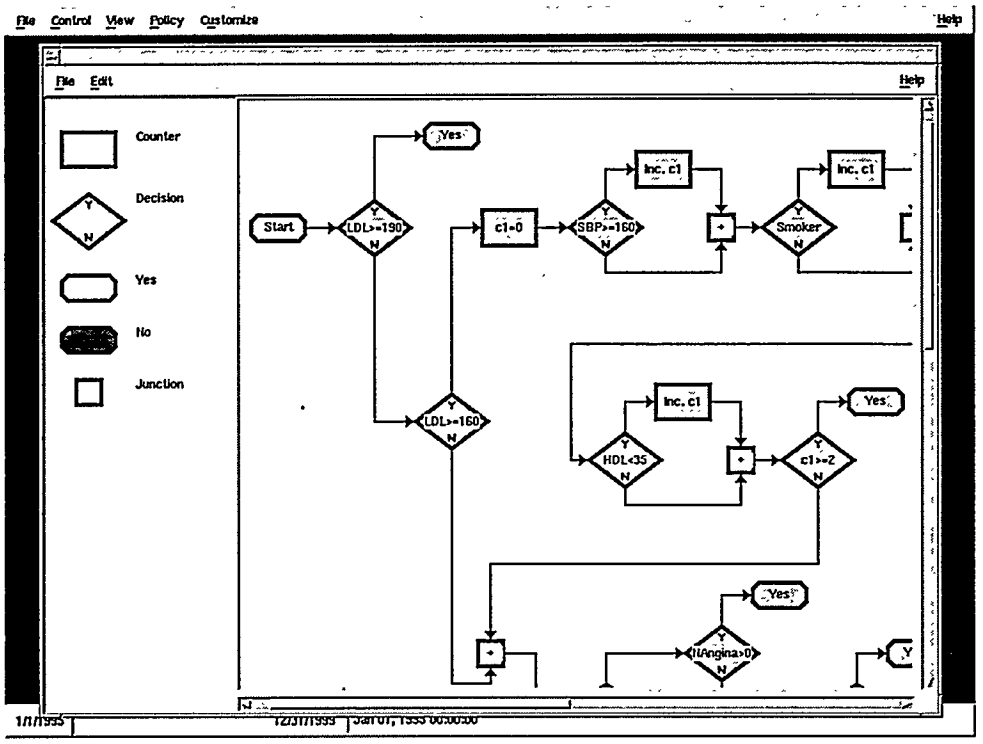


Figure A6. Patient Selection Flowchart



To run the simulation, select **Open Control Panel** from the **Control** menu to bring up the control panel, then hit the **Run** button (Figure A7). As the simulation runs, any open viewers or monitors will be updated with information corresponding to the current simulation time. In our example, the monitors for patients 976 and 1976 will fill with descriptions of events as they occur to each of the patients. We notice that patient 1976 in KP 2 participates in the cholesterol screening program and is treated for high cholesterol. Although eventually both patients die from heart failure, the cholesterol treatment appears to have prolonged the life span of patient 1976. The simulation runs until the stop time indicated on the control panel, which in this case is December 31, 2004.

A useful summary of the health and financial outcomes for each HCO can be displayed by clicking on the **Summary** icon in the each HCOs viewer (Figure A8). In our example, we find that the number of CVD interventions have been decreased by the cholesterol screening program in KP 2, with a slight increase in total costs associated with CVD screening and treatment. We also note that waiting times in KP 2 have increased with the additional load of screening and treatment appointments. Clicking on the **Show Report** button at the bottom of the HCO viewer will bring up more detailed information in the form of HTML documents (Figure A9).

Figure A7. Control Panel

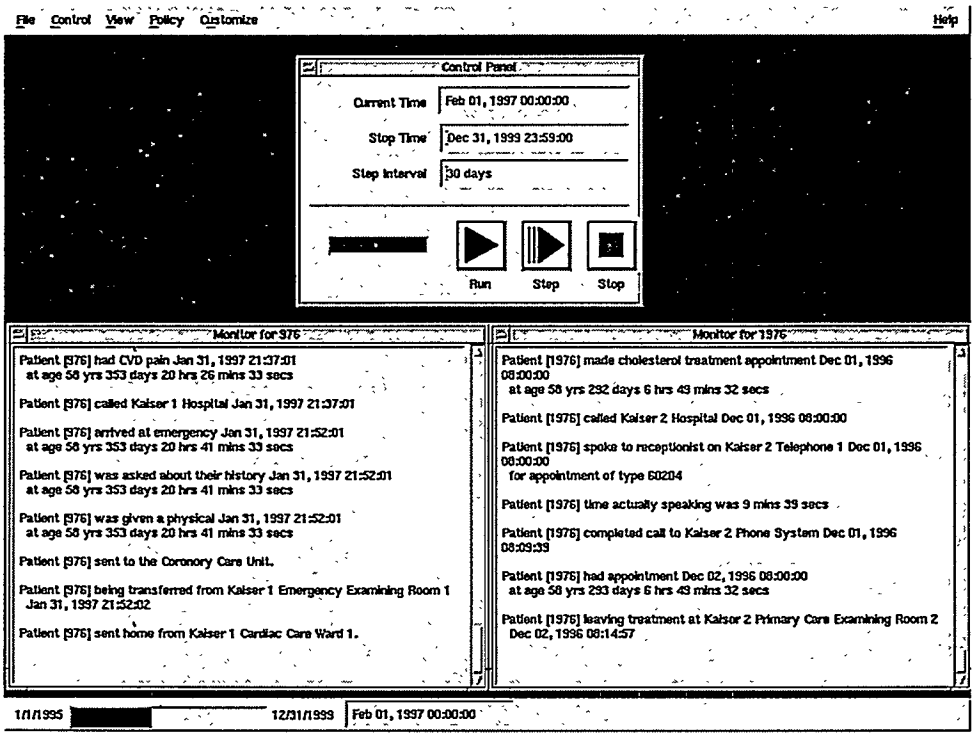


Figure A8. HCO summary

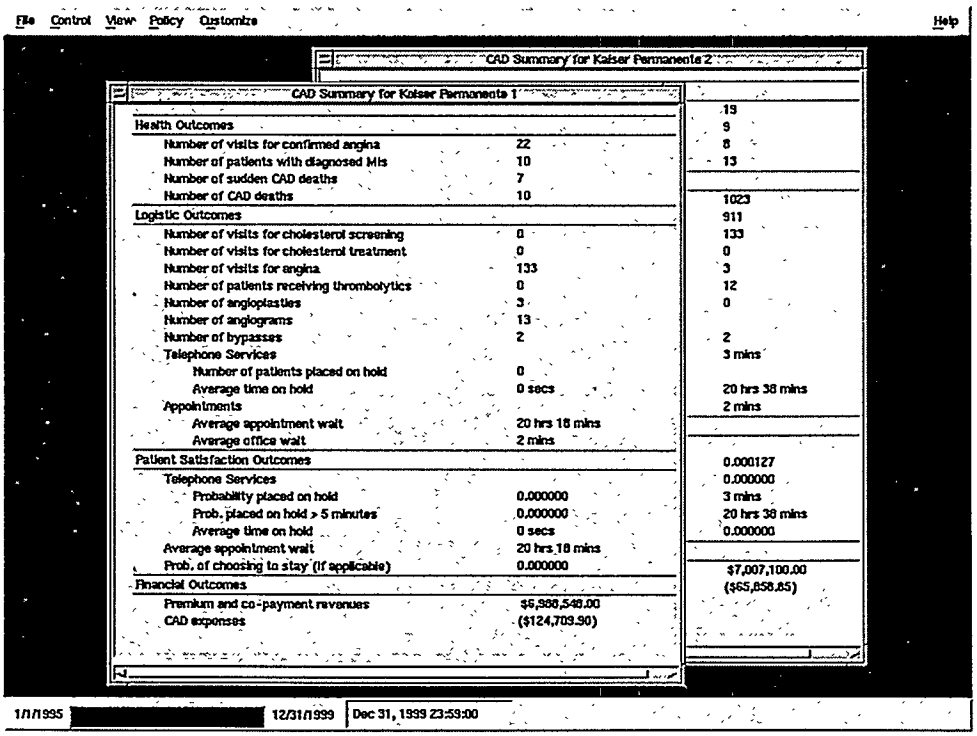
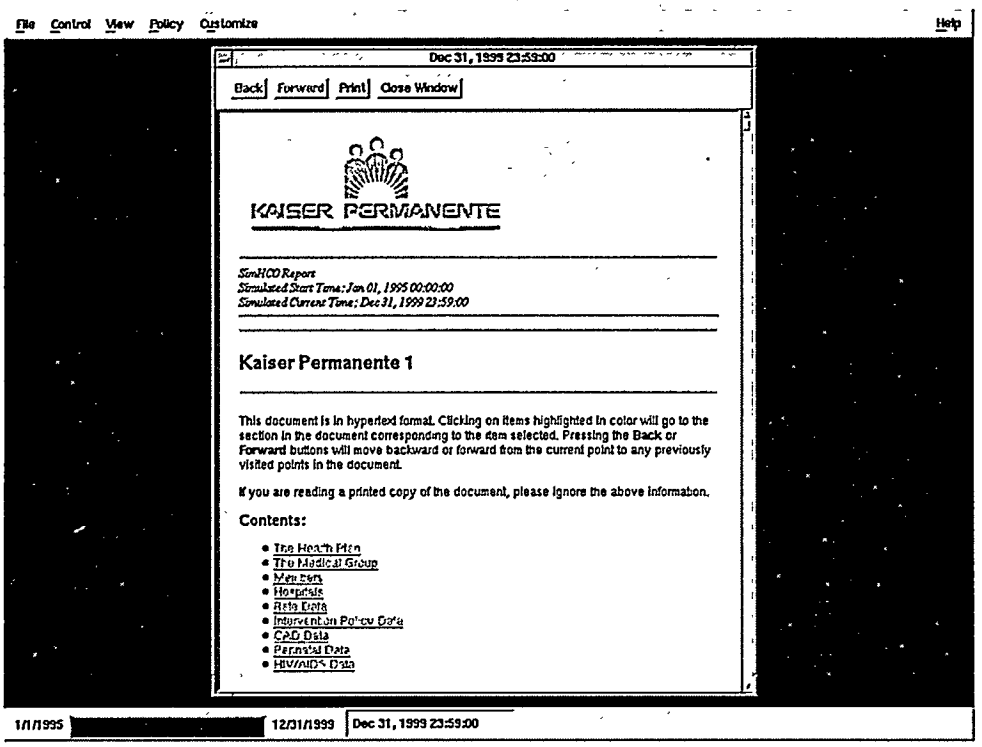


Figure A9. HCO report



B. Reference

This appendix describes the functionality of each of the menu items.

Main Menu

The main menu is located at the top of the main window. It consists of the following items:

File

Read Patients Database

Opens the File Selector.

The File Selector lists available patient database files. A file is chosen by clicking on its name, then clicking on the "OK" button. The file is then read and SimHCO is initialized.

Quit

Ends the SimHCO session.

Control

Open Control Panel

Opens the *Control Panel* (Figure B1).

The *Control Panel* is used to start and stop the simulation. It consists of the following fields and buttons:

Current Time

Displays the current simulation time.

Stop Time

Used to enter the desired simulation end time.

Step Interval

Used to enter the desired time step interval. When the simulation is running, all open viewers are updated at the end of each time step interval.

Run

Starts the simulation running.

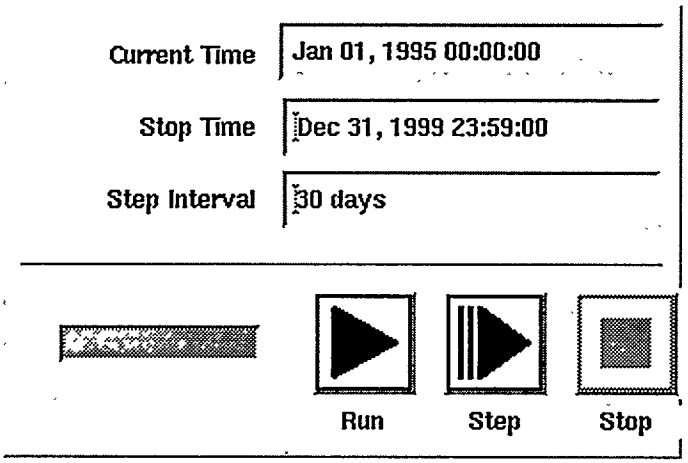
Step

Runs the simulation for one time step interval.

Stop

Stops the simulation.

Figure B1. Control Panel



Edit Simulation Parameters

Opens an *Editor* for the simulation parameters.

View

Open Browser

Opens the *Browser* (Figure B2).

The *Browser* is used to inspect the objects in the HCO. Objects are represented by icons that are arranged in a hierarchical structure. A "plus" sign to the left of an icon indicates the object consists of sub-objects. Clicking on the sign expands the object by showing icons for all of its sub-objects below it.

Clicking on an icon pops up a *Viewer* for the associated object.

Viewer

An object *Viewer* displays the attributes of the object. Sub-objects are represented by icons. Clicking on one of these icons pops up a *Viewer* for the corresponding sub-object.

At the bottom of the some *Viewers* are buttons that are used to display further information about the object. For example, *Viewers* for facility objects such as Hospitals and Departments have a "Show Report" button. Clicking on this button pops up an HTML format status report for the facility (Figure B3).

Figure B2. Browser and Viewer

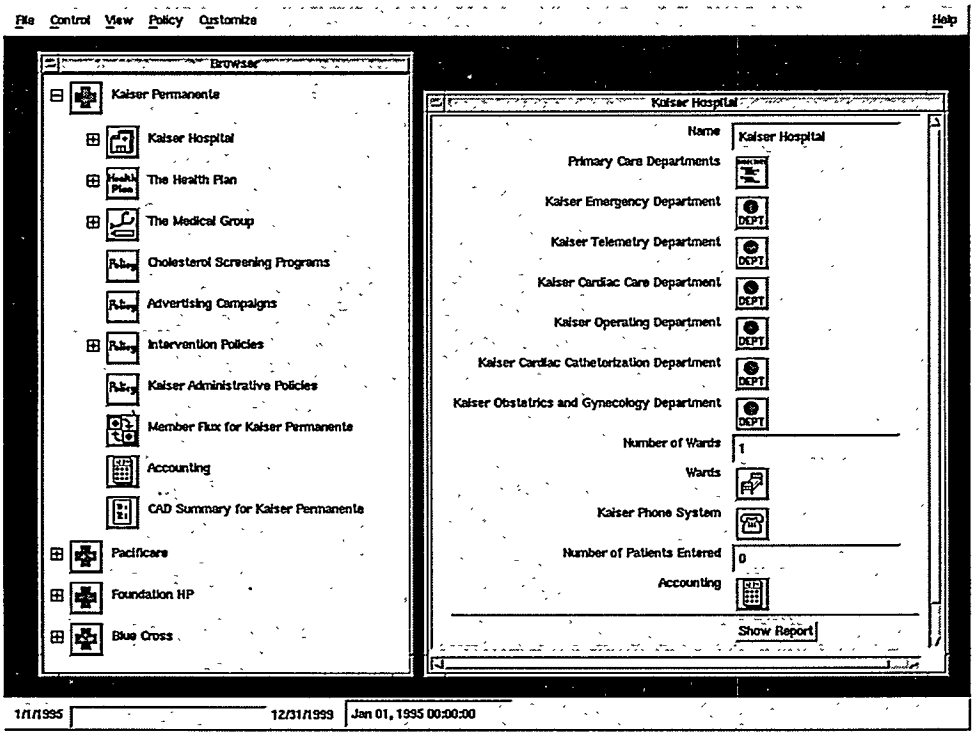


Figure B3. Hospital Report

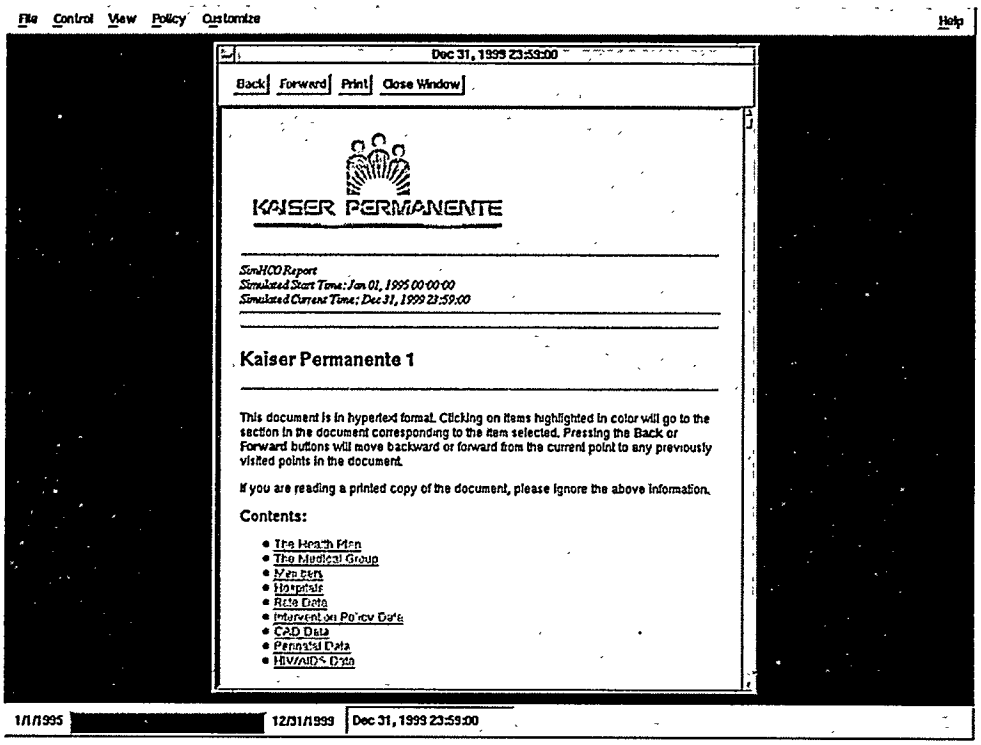
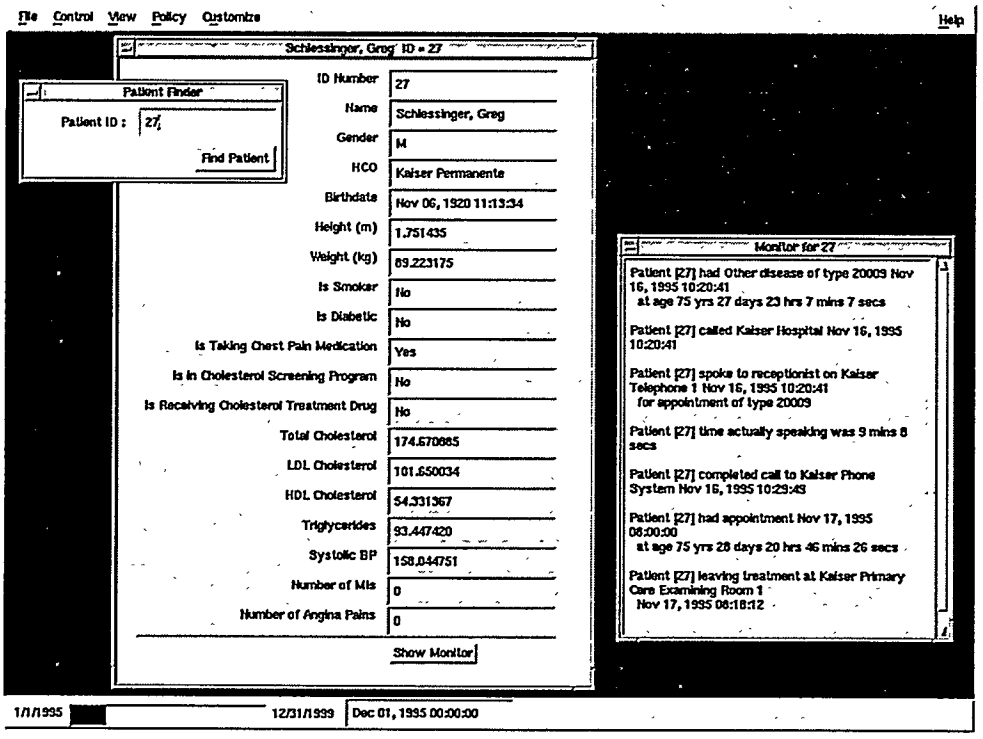


Figure B4. Patient Finder, Viewer, and Monitor



Find Patient

Opens the Patient Finder (Figure B4).

The Patient Finder is used to find a patient based on his or her unique identification number. After entering the identification number into the text field of the Patient Finder, clicking on the "Find" button pops up a Viewer for the corresponding patient. Near the bottom of the Viewer is a "Show Monitor" button. Clicking on this button pops up a Monitor that displays a text record of events as they happen to the patient.

Create Patient Histogram

Opens the Patient Histogram Creator (Figure B5).

The Patient Histogram Creator is used to create a histogram based on a patient attribute. The attribute is chosen by clicking on the "Histogram Type" button, then clicking on the desired attribute from the list that appears.

Filters may be used to tailor the histogram to sub-populations of patients. A filter is activated by clicking on its square box to "check" it, then specifying the acceptable values for the filter. For filters with discrete values (i.e. Gender, Smoking Status, etc.), all possible values are shown when the filter is active. Acceptable values are indicated by "checking" their respective boxes. For filters with continuous values (i.e. Age, Total Cholesterol, etc.), two text fields are shown when the filter is active. The acceptable range of values is specified by entering its minimum and maximum values into the text fields.

Clicking on the "Create Histogram" button produces the histogram.

Create Plot

Opens the Plot Creator (Figure B6).

The Plot Creator is used to create an x-y plot based on patient attributes. The attribute to be associated with the y-axis is chosen by clicking on the "Vertical Axis" button, then clicking on the desired attribute from the list that appears. The attribute for the x-axis is chosen in similar fashion with the "Horizontal Axis" button.

Filters may be used to tailor the plot to sub-populations of patients. The use of filters is the same as with the Patient Histogram Creator (see above).

Clicking on the "Create Plot" button produces the plot.

Figure B5. Patient Histogram Creator

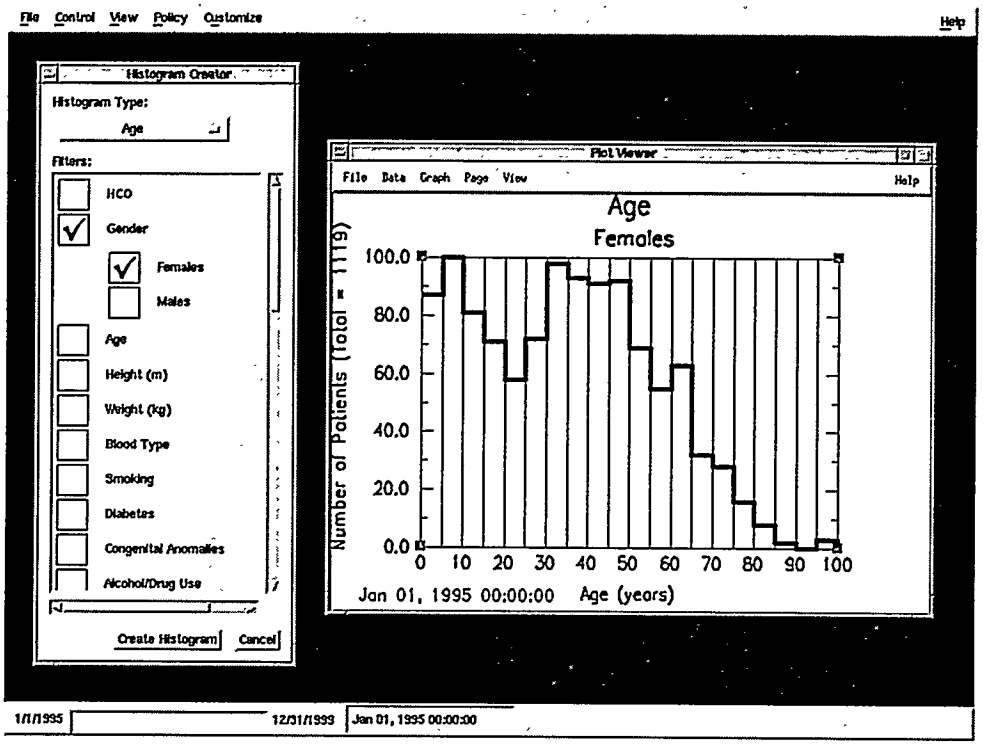
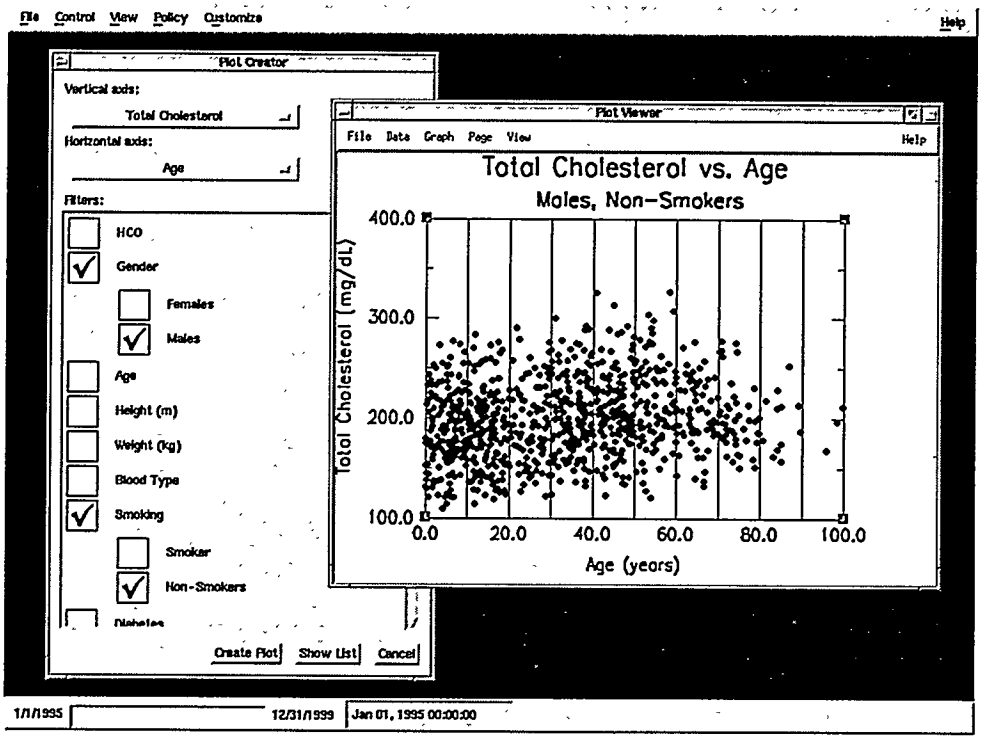


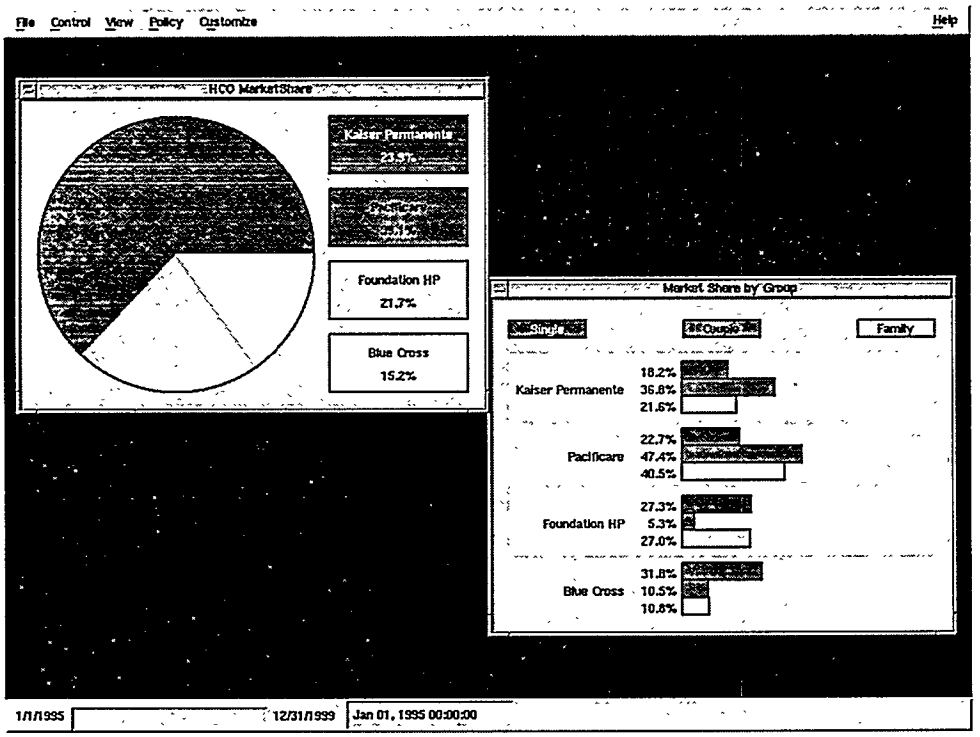
Figure B6. Plot Creator



Show HCO Market Share

Displays the patient market share for all HCOs in the simulation (Figure B7).

Figure B7. HCO market share



Show Market Share By Group

Displays the patient market share for all HCOs in the simulation, broken down by subscriber group type.

Policy

Programs/Campaigns

Used to implement new cholesterol screening programs or advertising campaigns.

Displays a list of HCOs in the simulation. The HCO is chosen by clicking on its name, then clicking on the "OK" button. A list of programs and campaigns is

then displayed. A program or campaign is selected by clicking on its name, then clicking on the "OK" button.

If "Cholesterol Screening Program" was chosen in the previous step, the *Cholesterol Screening Program Creator* is displayed (Figure B8). A custom cholesterol screening program is designed by editing the information displayed on this creator. Clicking on its "Accept" button implements the new cholesterol screening program.

If "Advertising Campaign" was chosen, the *Advertising Campaign Creator* is displayed (Figure B9). A custom advertising campaign is designed by editing the information displayed on the creator. Clicking on its "Accept" button implements the new advertising campaign.

Figure B8. Cholesterol screening program creator

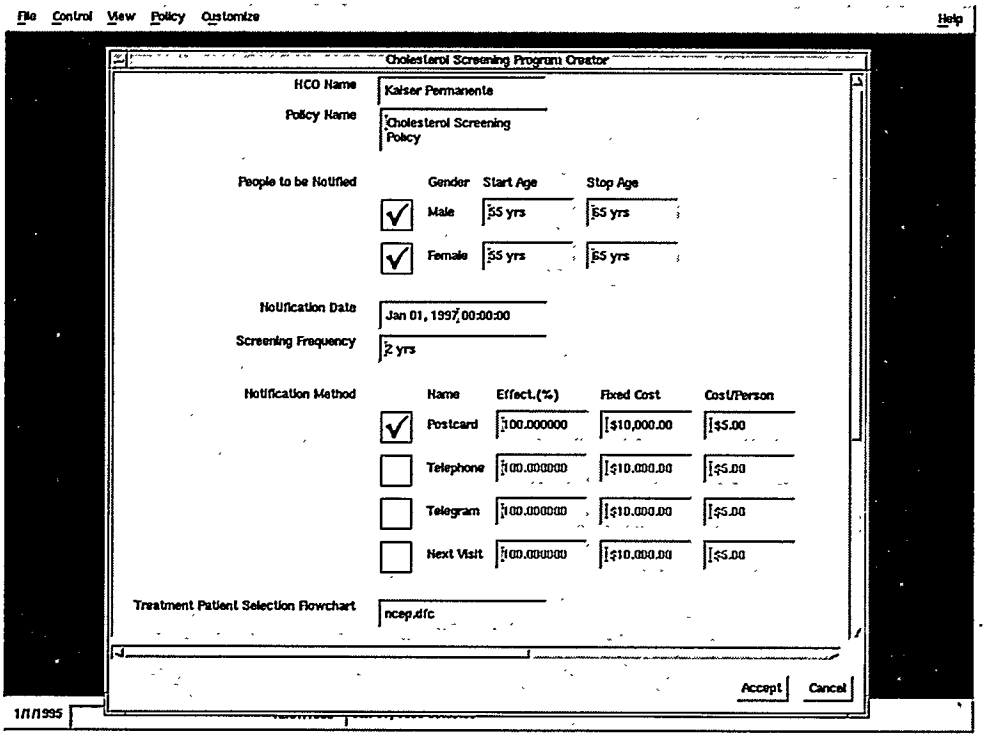
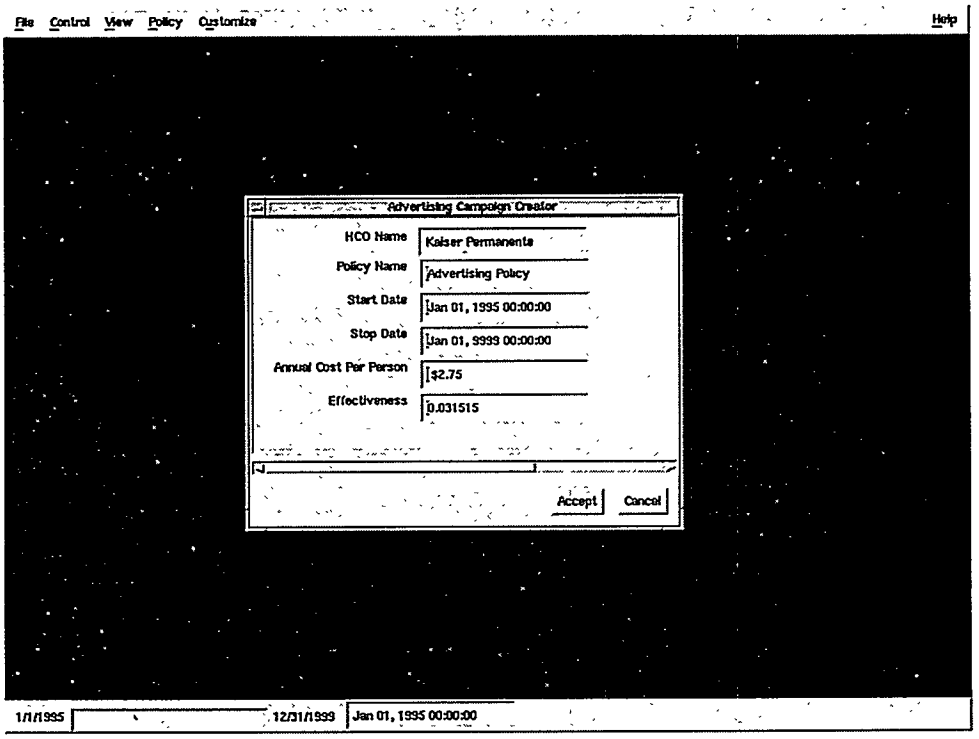


Figure B9. Advertising campaign creator



Patient Selection Flowcharts

Opens the Patient Selection Flowchart Editor (Figure B10).

The Patient Selection Flowchart Editor is used to create and edit flowcharts that specify patient selection criteria. These flowcharts may be used as selection criteria within various policies, programs, and campaigns. Directions for the editor are as follows:

To **add** an icon to the flowchart, drag an icon from the palette (area on the left) onto the work space (area on the right).

To **connect** icons, drag an output port (arrow points away from icon) onto an input port (arrow points toward icon).

To **edit** an icon, click on the text on the icon, then release on the Edit button.

To **delete** an icon, click on the text on the icon, then release on the Delete Icon/Confirm button.

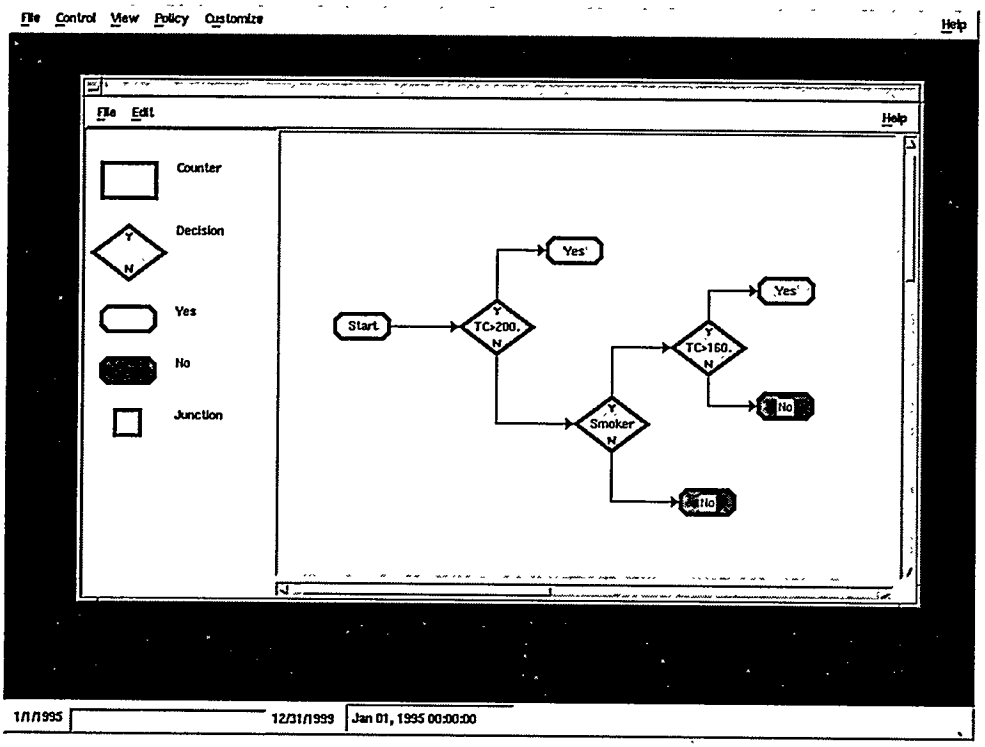
To **delete all** icons in the flowchart, select Clear from the Edit menu.

To **load** a previously saved flowchart, select Open... from the File menu.

To **save** the current flowchart, select Save from the File menu.

To **save** the current flowchart with a **new name**, select Save As... from the File menu.

Figure B10. Patient selection flowchart editor



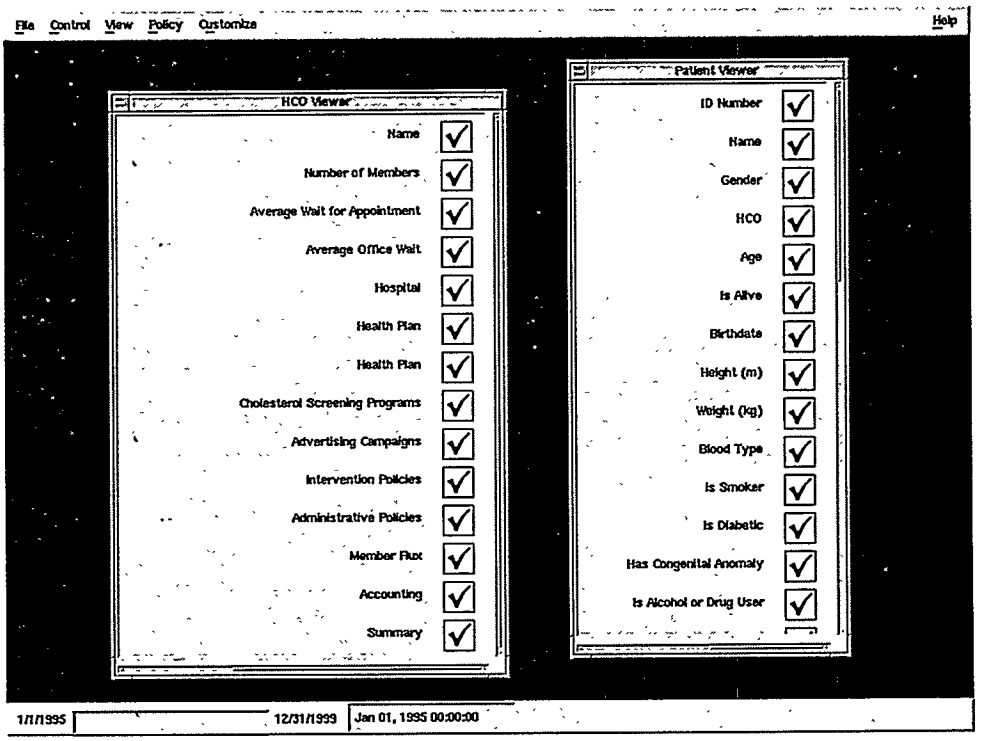
Customize

Used to customize the object *Viewers*. Selecting one of the listed *Viewer* types displays a list of object attributes that can be displayed in that type of *Viewer* (Figure B11). Clicking on the square box beside an attribute selects ("checked") or deselects ("unchecked") the attribute for display in a *Viewer*.

- HCO Viewer
- Hospital Viewer
- Department Viewer
- Examining Room Viewer
- Summary Viewer
- Waiting Room Viewer
- Ward Viewer
- Ward Room Viewer

- Health Plan Viewer
- Medical Group Viewer
- Accounting Viewer
- Patient Viewer

Figure B11. Customize object viewers



Help

Tutorial

Displays a brief tutorial on running SimHCO.

On Version

Displays SimHCO version information.

Information

Displays information about the developers of SimHCO.

Status Bar

The status bar is located at the bottom of the main window.

On the left portion of the status bar is a rectangular shaped *Run Status Indicator*. The dates shown to the left and right of the indicator are the start and stop dates for the simulation. A blue bar in the *Run Status Indicator* represents the portion of the total run time (the difference between the stop and start dates) that has already been simulated. When the simulation is running, a yellow bar represents the time segment that is currently being simulated.

The text field on the right portion of the status bar displays the current simulation time. This corresponds to the end position of the blue bar on the *Run Status Indicator*.

General Notes

Mouse Buttons

"Clicking" is always done with the LEFT mouse button.

"Dragging" is done with the MIDDLE mouse button.

Text Fields

A white background color in a text field indicates that data may be entered into the field. Data is entered by clicking once on the field, then typing using the keyboard.

A gray background color in a text field indicates that the field is for output only.

A red background color in a text field indicates that the data entered is not acceptable.

When an age or time period is entered into a text field, the units of time must be specified (e.g. 6 *months*, 18 *years*). If no units are specified, the age or time period is interpreted as 0, regardless of the number entered.

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