THE APPLICATION OF GPSS TO MULTIPHASIC HEALTH EVALUATION CLINIC DESIGN

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This paper discusses results of a study aimed at establishing an effective functional design and staffing pattern for multiphasic health evaluation (MHE) units -- a design maximizing patient throughput, while minimizing both operational and capital cost expenditures. M.H.E. units consist of two phases - a battery of medical screening tests and a physical examination. System sizing was dependent on the number and availability of second phase nurse practicioners to complete the physical exams. A GPSS model was developed to analyze two types of Phase I MHE configurations: carrel testing and sequence testing. Patient arrivals were asssumed Poisson, and service times were modelled as deterministic (machine dependent) or exponential (staff dependent). Varying patient volumes were modelled and staffing and machine requirements were determined at each level. The study resulted in a 45 percent reduction in required square footage as well as reduced equipment needs and costs.

I. INTRODUCTION

The Kaiser-Permanente Medical Care Program, headquartered in Oakland, Ca., is a Health Maintenance Organization presently comprised of eight Regional areas covering seven states from Hawaii to Washington, D.C. The Southern California region, serving over 1.5 million members from Los Angeles to San Diego, currently consists of eight medical centers and 33 satellite clinics providing in-patient (acute) and out-patient or ambulatory medical care and services to members.

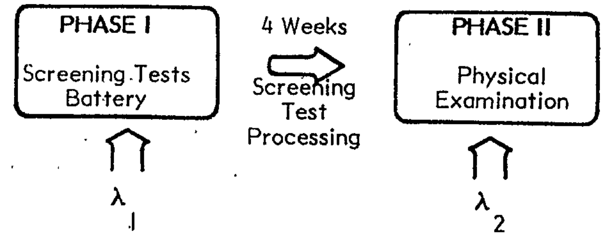
In serving its member population, the Kaiser-Permanente Medical Care Program has accepted and delt with the responsibility for providing high-quality medical care to large numbers of patients in a fast, convenient and cost-effective manner. This responsibility has required the Program to maintain a continual process for planning and constructing both services and facilities to meet membership needs.

During plans for a new multi-tower satellite clinic, one of the eight Southern California Regional medical directors requested assistance in several areas from the Region's Management Engineering Department. These areas included facilities layout, patient and staff traffic flow, work station layout and design along with general logistics and area proximity plans throughout the new clinic.

One area planned for this new clinic was a high-volume multiphasic health evaluation (i.e., MHE) unit to handle 150 patients daily. The mission of this new MHE unit, as with traditional MHE philosophies (Collen, M.F., 1978), was to provide new members with an entry point into the program, via an initial ambulatory testing and examination process. This process is typically aimed at screening for and pinpointing patient's general medical problems and deficiencies, with subsequent referrals made to other medical specialty departments for indepth diagnostic follow-up and treatment.

Multiphasic health evaluation (MHE) units are generally organized as a two-phase operation. Phase I includes a patient orientation session to MHE concepts, coupled with a battery of screening tests. Phase II, normally following four weeks after Phase I, then provides patients with a physical examination, discussion of Phase I test results and directions for follow-up care. An important point here is that Phase II patient capacity must be designed to match that of Phase I testing, to maintain this four-week lag at a constant level as shown in Exhibit I-1.

EXHIBIT I-1
Relationship of Multiplasic Unit Phases I and II



The Phase I test battery at a MHE unit is typically planned around two points. First, generic tests are selected, with most batteries covering nine target areas:

- Visual Acuity;
- Tonometry;
- Audiometry;
- Pulmonary Function;
- Vital Signs (height, weight, blood pressure, temperature);
- Urinalysis;
- Blood;
- X-Ray;
- ECG (EKG);

The second point in Phase I planning turns on choice of method for organizing patient flow through the test battery. In general, two options are available (Collen, M.F., 1978) and defined as:

- Sequence testing: Patients travel from one test station to another. Here, each station may have its own test technician, or the same technician may move from station to station with a patient;
- Carrel Testing: A selected group of tests are combined in one room or station, all grouped tests conducted by one test technician on a given patient.

Exhibits I-2 and I-3 show the general flow for both sequence and carrel testing options and basic test areas included in a typical MHE unit.

EXHIBIT I-2

SEQUENCE TESTING FLOW
PHASE I
MULTIPHASIC UNIT

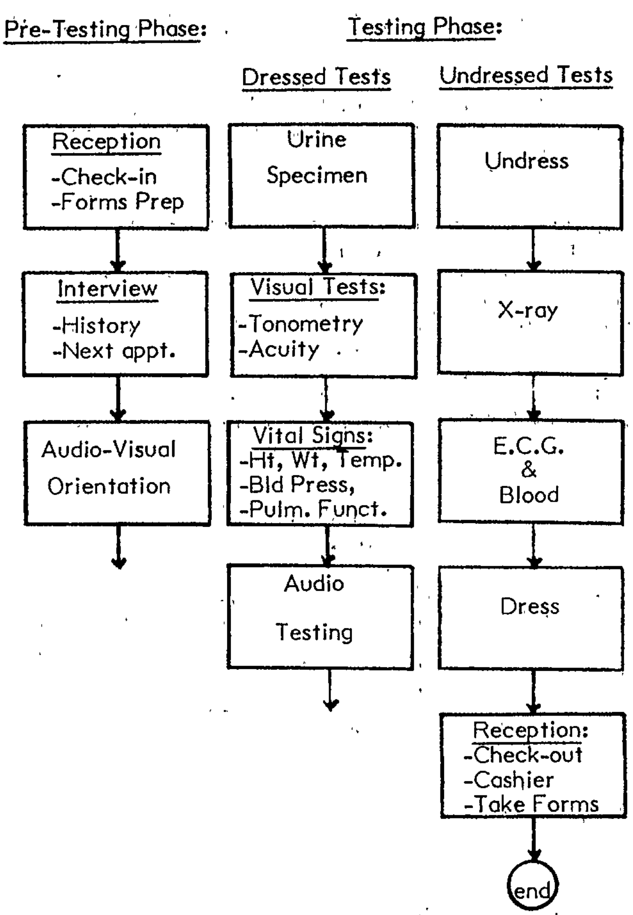
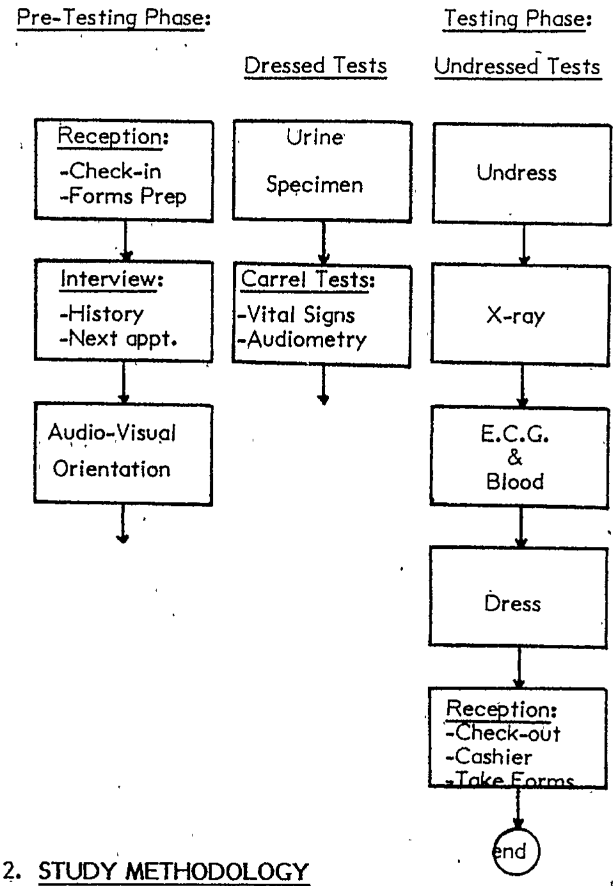


EXHIBIT I-3

CARREL TESTING FLOW
PHASE I
MULTIPHASIC UNIT



2. STUDY METHODOLOGY

After determination of the MHE unit medical director's objectives and departmental mission, a general pattern of tests to be included in the system was developed. Three MHEs were in operation within the Kaiser Permanente Southern California Region. These facilities were the primary data collection sources for the evaluation of present methods and procedures and the development of standard times for related tasks.

Initially, each clinic was analyzed to determine the types of tests completed, equipment used, patient/visitor/staff flow, layout, and test selection criteria. These data were documented for each clinic and presented to the planned MHE's administration. A critical segment of design was the equipment selected for each test. Some criteria used to determine equipment were:

- Cost of equipment;
- Operational implications (i.e.; complexity of use, cycle time, size);
- Sensitivity, and;
- Maintenance requirements.

The tests that were evaluated for equipment alternatives included:

- Pulmonary function;
- Audiometry;
- Visual acuity and;
- Electrocardiogram (E.C.G.).

Differences in specific equipment had considerable effects on service times and potentially on patient throughput. MHE administration made decisions on each specific equipment selection point.

Detailed flowcharts were constructed containing all proposed segments of the MHE. These flowcharts included decision points for test selection criteria as well as for each service area. Specific task methods and procedures used on the selected equipment were also documented and evaluated to incorporate any possible alternative methods of operation.

These flowcharts were then used to determine job specific tasks for each MHE segment. Stopwatch time studies were then completed for each test segment. The time studies generated average service times by task, and were then converted into standard times using a twenty (20) percent personal, fatigue, and delay allowance. Additionally, man-machine activity diagrams were constructed on each system segment to determine the limiting factor in service time. Table M-1 contains limiting factors and standard times for each test type.

TABLE M-1

Standard Times and Limiting Factors of Phase I Multiphasic Test Battery Components

Test Component	Standard time (in minutes)	Limiting Factor
Check in/Reception	4.2	Staff
History and Interview	7.0	Staff
Audio-visual Orientation	7.6	Machine
Urine Specimin Collection		
- Male	4.4	Patient
- Female	2.6	Patient
Visual Acuity & Tonometry	3.0	Machine
Vital Signs	3.2	Staff
Pulmonary Function	2.6	Machine
Audio Testing		
- Booth	12.0	Machine
- Manual	0.7	Machine
Undress time	3.3	Patient
X-Ray	3.0	Machine
EKG (12 lead)	4.0	Machine/Staff
Venipuncture (blood)	3.0	Staff
Check out	1.0	Staff

Upon completion of the site visits, equipment selection, and data collection, the expected outcomes of the model were defined. It was the study team's goal to maximize the patient throughput while minimizing both construction and operational costs. Additionally, a policy decision on the type of MHE system to be used - carrel versus sequence testing was desired. The evaluation of these two systems required a multi-track approach to the actual modelling. Definitive staffing requirements at varying patient volumes were also desired. These staffing requirements would be system specific, and would serve as the operational payroll budget upon MHE opening. The equipment requirements were also to be derived from the results of the model.

2.1 Model Development

The MHE concept is similar to many industrial-type high volume service system applications. The patient arrival assumptions were limited to the arrivals at the beginning of the system (receptionist). Initially, the system was modelled assuming that arrivals constitute a Poisson process with intensity parameter (arrival rate) λ .

Therefore, for the given time interval $(0,t]$, the number of events occurring during that interval had a Poisson distribution with a mean of λt. Consequently, the times between successive Poisson arrivals (interarrival times) were stochastically independent with a negative exponential waiting time distribution given by:

$$P(x) = 1 - e^{-\lambda t} \text{ for } t \geq 0$$

This assumption seems to hold true for the patient arrival scheme noted in most clinic-type situations. Despite the fact that all patients in an MHE have appointments, empirical data show that their actual arrivals were distributed as Poisson around some mean arrival time.

The distribution of patient service or processing times was a more complex issue to address. Initially, it was hypothesized that the service times were exponential in nature, implying a M/M/m system. As a result, the network of subsystems (tests) that made up the MHE would follow Burke's theorem which states: Poisson arrivals with exponential service times produce Poisson-like departures (thus Poisson-like arrivals at the next subsystem). However, a large percentage of the service times were machine cycle times, thus seeming to be more deterministic in nature.

Therefore, the use of exponential service times for all subsystems was felt to have unpredictable shortcomings. The resulting arrivals at any point in the service network could not be assumed Poisson. Thus, it was decided that a group of scenarios be developed to test the different MHE models. Those scenarios were validated through the modelling of an existing MHE and the comparison of those scenarios with empirical data from the tested MHE.

In order to compare relative outcomes as well as to obtain a first cut for system requirements, an M/M/m queueing model was used to determine system requirements. This initial model provided two pieces of data:

1) Once simulated using GPSS with Markovian arrivals and service rates, how close do the two models hold? (Thus, a reconfirmation of Burke's theorem), and;

2) What effect does a mixture of service distributions have on the total service time compared to the exponential-across-the-board assumption? (How closely does the M/M/m system approximate actual and how sensitive are each segment of the model?).

The assignment of GPSS modelling entities was then completed for each model component. The model components and their associated GPSS entity can be found in Table M-2. Additionally, each segment's waiting time was measured using QUEUE and QTABLE blocks. These data provided definitive waiting time distributions which were used to determine the operational and capital costs associated with decreasing patient wait times by some percent, P.

TABLE M-2

Component Modelling Entities

Model Component	Modelling Entity	Range of Servers
Reception	STORAGE	1-3
Audiovisual Orientation	STORAGE	3-8
Urinalysis	STORAGE	3-8
Carrel	FACILITY	1
Visual Acuity	STORAGE	2-3
Vital Signs	STORAGE	2-3
Audio Booths	STORAGE	3-8
Dressing Rooms	STORAGE	6-12
ECG/Phlebotomy	STORAGE	2-8
X-Ray	FACILITY	1

The modelling of the carrels - where a battery of tests were completed in one room - was done using a SELECT block. The use of a SELECT block and the assignment of a specific FACILITY showed the utilization of the carrels compared to each other. As a result, a determination could be made as to decreasing the number of servers to increase utilization thus decreasing both operating and capital costs. Measuring of the net effect of the decrease on total unit and service time was also available.

The sequence testing model contained each specific test modelled separately. Staffing in the sequential model was assumed not to be the limiting factor. As a result, STORAGE blocks were used to encase the specific segments of code that related to staffed tests. An example of this can be found below in Exhibit M-1.

EXHIBIT M-1

Code Segment Used to Determine Staffing

```
ENTER     STAFF
QUEUE     CARQ
ENTER     CARRL
            :
LEAVE     CARRL
LEAVE     STAFF
```

By using the average occupancy of the facility STAFF the appropriate number of clinic assistants to handle the given patient load was determined, in this case for the carrel testing method.

Both models used selection criteria for which patients had electrocardiograms (EKGs) performed. The selection criteria for performing EKG's were:

- Males over the age of 35;
- Females over the age of 40 or;
- Anyone with a previous history of cardiac problems.

Membership data were used to determine the percent of patients that fell into one of the first two categories. The percentages were used with TRANSFER blocks in the statistical mode to allocate workload to these areas.

2.2 Model Runs

Initially, the model for both sequence and carrel was run using the number of servers derived from the M/M/m queueing theory formulae. Snap intervals were taken to measure the state of the system at different times in the modelled day. On all runs, the system was loaded by using the following segment of code:

```
START    10, NP
RESET
START    100
```

By using this segment of code, more "typical" operating conditions existed, and the initial bias was removed from the statistics (i.e.; waiting time and utilization statistics being lower because the initial empty system was avoided).

After the initial formulae-based run, increased server sensitivity for each segment was used in the multiple run mode of GPSS. This provided a timely and cost effective method to obtain the data. The multiple run mode allowed more than one run to be executed once the program was loaded, thus decreasing the required resource consumption to run the program. Additionally, varying arrival rates were used to determine staff and equipment requirements and utilization at different patient volumes.

3 RESULTS

3.1 Model Validation

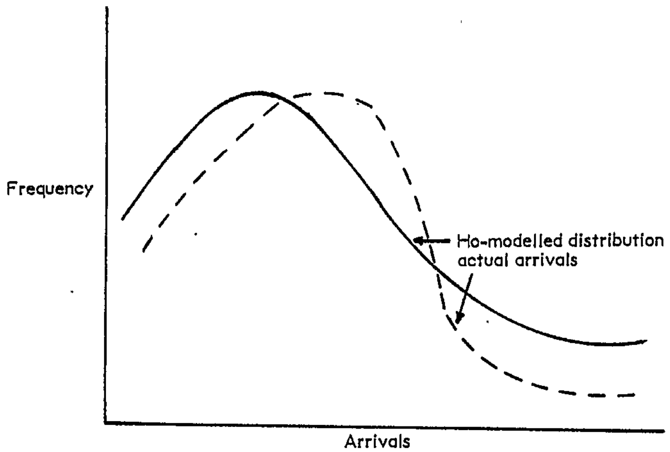
In order to validate the GPSS technique, an existing MHE was modelled. The MHE modelled was a carrel-type operation seeing approximately 75-80 patients per day. Empirical data were collected on patient interarrivals, queue lengths, and system service time using work sampling techniques and stopwatch time studies. The empirical data were compared with the results of the simulations, given the different modelling scenarios and the arrival rate, λ , associated with 80 patients per day.

The Kolmogorov-Smirnov test was applied (α = 0.05) to each category (total service time, T_q, L_q, and patient interarrivals) of empirical data given the range of distribution scenarios. The best fit was found in the M/ M-D/n model.

The results of this analysis supported the validity of the GPSS model using Poisson arrivals and a mixture of both deterministic and exponential service times. The use of Poisson arrivals and strictly exponential service times (M/M/n) was not as good a fit as the mixed deterministic-exponential service configuration.

Although the interarrival time modelled did not pass the K-S test at the given level of significance, it was felt that the input distribution still closely resembled the actual, as the problem of fit was generally found in the tails of the distribution. Exhibit R-1 shows a comparison of the hypothesized distribution with the actual distribution.

EXHIBIT R-1
Modelled versus Actual MHEC Arrivals



This initial model provided direction in determining the most valid input and service distributions to use in the MHE model. It was determined that no significant differences in methods and procedures existed that would make these assumptions less valid.

The outcome of the M/M/n queueing theory formulae, mentioned before, closely resembled the Poisson-exponential GPSS model when the queue lengths for specific system segments in the GPSS model approached zero. The queueing theory model, however, produced a more conservative estimate for service requirements than the GPSS modelled MHE using Poisson arrivals with a mixture of exponential and deterministic service times. It can be concluded that, though conservative, the M/M/n queueing theory formulae are a good first cut for system requirements. If available in a quickly accessible manner, these formulae can be used as a tool to determine initial server requirements and can be used as a starting point in the GPSS model.

3.2 Comparison of Alternatives

The carrel testing model was found to be the most effective model for patient volumes up to 150 patients per day. For volumes of greater than 150 patients per day, the sequential model was preferred. The overall patient service time was consistently lower for the carrel model up to 150 patients per day, where the sequence model showed a lower service time. In general, queues were lower in all comparative aspects of the carrel model. A summary of total service time, staff and equipment requirements can be found in Table R-1 for varying patients volumes for both sequence and carrel systems assumed by the GPSS model.

4. CONCLUSIONS

The outcome of the GPSS model provided a guideline for the development and implementation of MHEs in the Southern California Region of the Kaiser-Permanente Medical Care Program. Many MHEs were in the planning stages at the beginning of the study. The ability to improve patient and staff flows and optimize machine and staff utilization represented considerable cost savings and cost avoidances.

These cost savings fell into three categories: capital construction, equipment, and operational budgets. The capital construction budget for one MHE was decreased 45% from that originally allocated to the area. This reduction was directly attributed to the development of more precise resource needs through the discrete simulation process outlined here.

Since a major study goal was to maximize patient throughput, the question of equipment selection was highlighted in the simulations. The model enabled the study team to show the effect of a longer service time for a given machine on the overall service scheme. As a result, the equipment selected reflected the medical needs of the system without jeopardizing patient throughput. The cost savings in this area resulted from a reduction in the sensitivity of machines as well as a reduction in the quantity purchased.

TABLE R-1
Results of MHE Comparative Simulations

Patients Per Day	Carrel Testing			Sequence Testing		
	Required Number of Rooms	Total Average Wait Time (minutes)	Total Service Time (min)	Required Number of Rooms	Total Average Unit Time (minutes)	Total Service Time (min)
50	1	0.4	43.2	3	1.7	58.3
75	2	0.3	48.4	3	3.9	72.6
100	2	1.6	50.1	6	2.2	50.6
125	3	2.2	51.2	6	3.5	54.2
150	3	3.5	55.8	9	4.4	60.0
175	4	11.2	82.3	9	5.1	69.3

The operational budgets (and resulting employee productivity) were an essential by-product of the model. The ability to show administration exactly how many people were required to handle the patient load was a true selling point for the model. One point that was emphasized was that these staff requirements were determined under a certain group of assumed methods and procedures; these methods and procedures had to be implemented in the MHE to obtain full benefits from the simulation model.

To date, one new clinic has been completely designed and constructed to see 140-150 patients in Phase I per day using the carrel method. This clinic is presently using the modelled requirements and is experiencing no difficulty. An additional clinic (designed for 120-150 Phase I patients per day) is in the final phases of construction under the carrel model. After presentation of the simulation results to the medical directors of the existing MHEs, two clinics (both see 100 patients per day) which were operating under the sequence model have altered their practice to the carrel method. This change has resulted in considerable equipment savings, increased staff productivity (i.e., the same staff who treated 60 patients per day are now seeing 100 patients per day), and increased staff satisfaction.

In conclusion, the GPSS model provided the necessary flexibility to quickly change assumptions and model parameters at the clients' request, and show the net effect of policy decisions before they were implemented. The block structure of GPSS provided an invaluable tool in convincing the clients of simulation's applicability to such a system. The ease in interpretation of model structure and results made the actual computer output a viable source document for discussing clinic structure with administration.

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